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ISTHMIAN GEOLOGY AND THE PANAMA CANAL.

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INTRODUCTION.

In considering the Panama Canal from a geological point of view two matters are of special interest: the character of the foundations upon which locks and dams are to be built, and the natural resources of the country that may be drawn upon for building materials.

Some of the strongest objections that have been raised against a lock canal have been based upon the belief that no safe foundations are to be found for the dams and locks, and especially for those on the Atlantic side at Gatun. This belief has been a very general and persistent one; its origin is to be attributed largely to the misinterpretation by laymen of the technical reports of engineers, which, although essentially correct as regards facts, are, for lack of geological training, sometimes misleading in expression.

The writer was sent to the Isthmus by the Canal Commission in July 1906 to make a general study of the geology of the Canal Zone, and as the objects of the examination were strictly practical ones, special attention was paid to the dam and lock sites, and to the natural resources of the country. Nearly five months were devoted to the field work, and the following account, based upon the official report, is offered with the hope that it may lead

to a clearer understanding of some of the physical problems with which the engineers have had to deal.

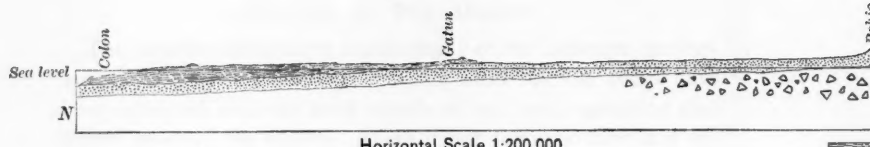
GEOLOGY OF THE REGION.

The greatest obstacles to a close study of the Isthmian geology are the widespread decomposition to which all the rocks have been subjected, and the thick mantle of soil and vegetation that covers most of the region. Were it not for exposures and excavation along the line of the Panama Railroad and the canal, and numerous borings, it would be difficult indeed to obtain any but the most meager information. The geology itself, so far as it has been deciphered, is not complex.

The oldest rocks are andesitic. They are tuffs and breccias with associated flows and occur in the central and southern portions of the Canal Zone. Resting upon these on the Atlantic or northern side of the Isthmus are fossiliferous conglomerates, sandstones and shales dipping at low angles toward the Caribbean Sea, so that in passing from the interior to Colon successively younger beds are encountered, the oldest carrying an Eocene fauna and the youngest late Oligocene, according to Mr. William H. Dall. On the southern or Pacific slope are similar rocks of Eocene age that disappear beneath beds of acid pyroclastics which in turn may be traced almost continuously for five miles from the point of first appearance to the shore near the Pacific end of the canal. Ancon Hill, which dominates the city of Panama, consists of massive rhyolite porphyry and it is believed that it marks the site of a volcanic vent from which the acid tuffs and breccias of the neighborhood were erupted. Tuffs of nearly the same composition are found on the Atlantic side in the vicinity of San Pablo and Tabernilla, and the occurrence of similar rocks at Gatun, interbedded with fossiliferous sediments of the Oligocene gives definite evidence as to their age. The deposits on the Pacific side are believed to be contemporaneous with those just mentioned.

Cutting all of these older rocks at innumerable points in the central and southern parts of the Zone are dikes and irregular

PLATE VIII.



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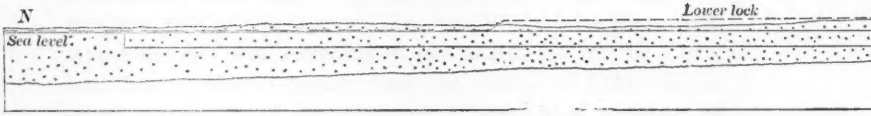

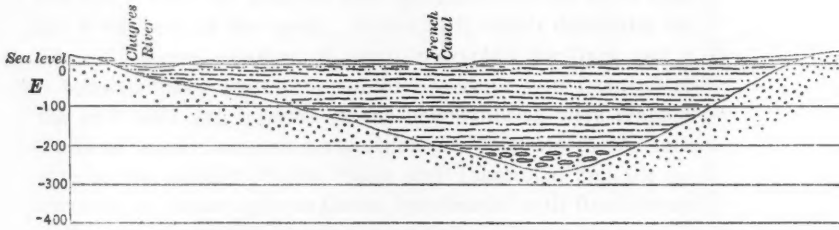

Horizontal and vertical scale the same in Figs.2 and 3.
1 inch= 400 feet

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FIG.1. GEOLOGICAL PROFILE ON CENTER LINE OF CANAL.

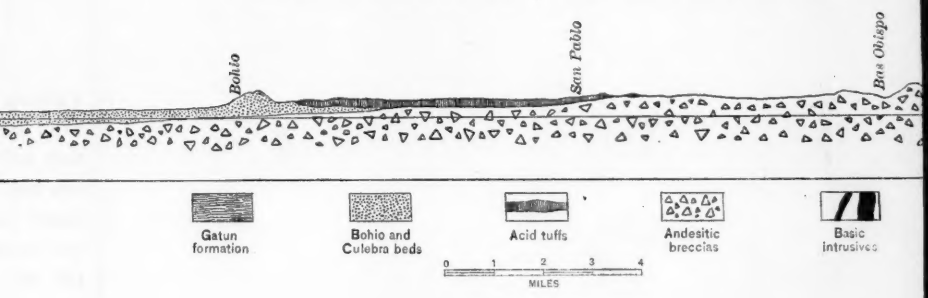


FIG.2. CENTER LINE, GATUN LOCK SITE.

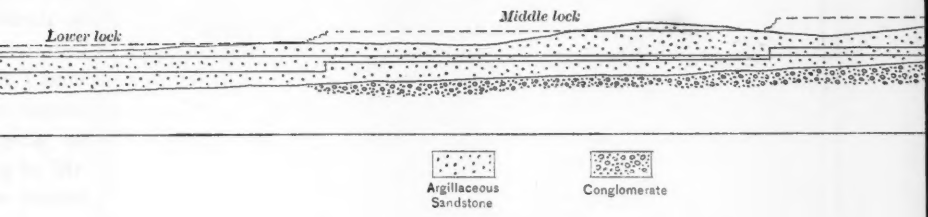
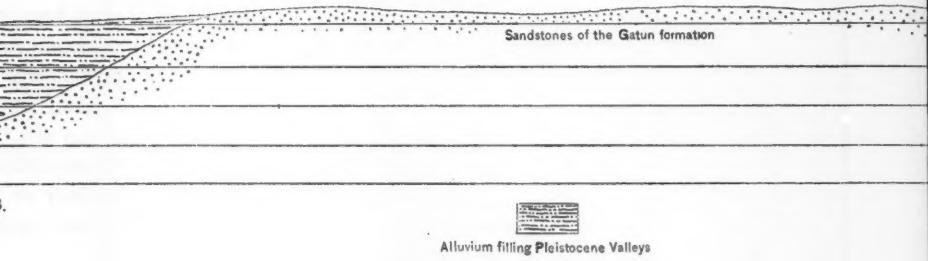
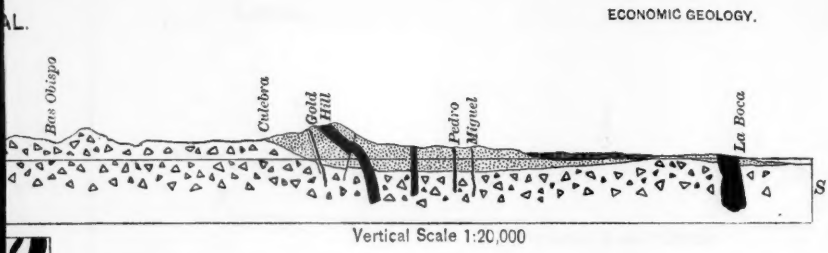


FIG.3. GATUN DAM SITE – PLEISTOCENE VALLEYS.



GEOLOGIC SECTIONS IN THE PANAMA CANAL ZONE.

By Ernest Howe.



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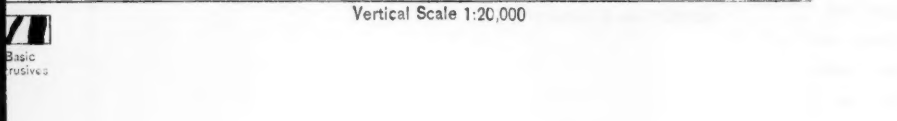

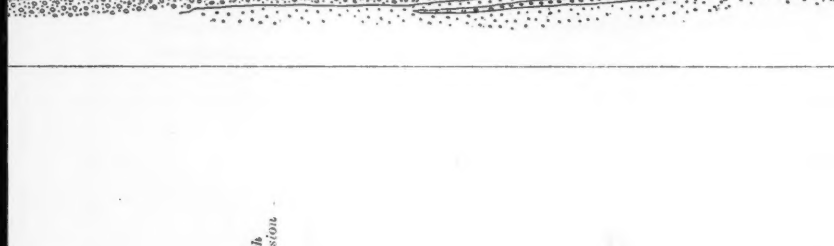

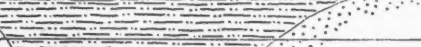

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stock-like masses of pyroxene-andesite and basalt. These are, so far as is known, the youngest rocks of the region, and the intrusions are believed to have occurred in Miocene time.

These relations are shown conventionally in the accompanying geological profile drawn on the center line of the proposed sea-level canal, Plate VIII, Fig. 1.

Structure.—The structural features of the section exposed along the canal line from north to south are in general simple, and appear to be those of a broad, flat arch or anticline having a nearly east-west axis. In the summit region the early andesitic breccias are exposed and dipping away on each side are the sediments. A more careful study of the early geologic history shows that differential movements of the land took place at intervals from the Eocene on, and that the apparently simple anticlinal structure is complicated by the presence of more than one unconformity. For the present purposes, however, the accompanying profile, with its vertical scale necessarily exaggerated, may be regarded as conveying a true idea of the structure; it only suggests the numerous masses of intrusive rock in the central and southern portions, and does not show the many small folds and faults associated with them. The folding and faulting find their best expression in the vicinity of Culebra, where the soft Eocene shales and sandstones have been disturbed considerably. Younger beds also have been affected both to the north and south, notably the rhyolitic tuffs near Panama and the corresponding beds on the Atlantic slope.

Development of the Present Topography.—Three well-marked epeirogenic movements occurred after the close of the basic intrusions, and the erosion that followed these uplifts developed the various topographic features of today. Practically no trace remains of the land surface that existed before the first post-Miocene movement; it was obliterated by the first period of erosion and the land reduced to baselevel.

As a result of the second movement the central portion of the Isthmian region was elevated to a greater extent than the land bordering either coast, and the warped peneplain more deeply

though less completely dissected in the interior than near the shores of the Atlantic and Pacific. The effect of this second uplift is well shown near Colon, where traces of the older peneplain are preserved in the nearly level summits of the Monkey Hills, that rise about fifty feet above the low plains and swamps formed in the second cycle of erosion. The present topography was developed largely during this second period, and the great variety of form is to be attributed to the differences in the physical character of the rocks. The presence of numerous igneous masses and cross-cutting bodies in the central portions is responsible for the innumerable sharp conical hills that are so characteristic of the Isthmian scenery in the Culebra region. The lower valley of the Chagres below San Pablo has been eroded in the soft Tertiary sediments and is wide and open except where more resistant rocks occur as at Bohio and Gatun.

The second cycle of erosion had progressed far enough for the principal streams to have reached a condition of grade for twenty miles or more back from their mouths and for such distances they meandered over broad floodplains. At this stage a third and comparatively sudden uplift occurred by which the land was elevated more than three hundred feet, the streams revived, and narrow valleys cut below the level of the former floodplains. While these valleys were still young the land began to sink slowly, the valleys or canyons were aggraded, and, in the continued subsidence, the lowest portions of the older floodplains were submerged and covered to a depth of a few feet with estuarine deposits. A fourth upward movement has raised these deposits a foot or two above high tide level. The broad low plains and swamps that extend back from Limon Bay and border the Chagres nearly to Bohio are largely of this alluvial character and there is nothing on the surface to indicate the presence of the ancient gorge. It has been discovered and located entirely by means of borings, and samples of shells brought up from considerable depths below sea level show that the filling of the old valley took place in Pleistocene time. This buried Pleistocene valley is one of the most important geological

problems with which the engineers of the canal have to deal, and it is described in detail in a later paragraph.

GEOLOGY OF THE CANAL.

INTRODUCTORY.

It will be recalled that the type finally adopted by the Commission, and approved by Congress in June, 1906, is that of a lock canal having a summit level of 85 feet above mean tide.

On the Atlantic side there will be an approach at sea level of about four miles, from Limon Bay to Gatun, where a great earth dam across the valley of the Chagres will form a lake 171 square miles in area. The normal level of the lake will be 85 feet above mean tide and will be reached by a flight of three locks in duplicate at Gatun. Beyond the locks there will be open lake navigation for over 20 miles to the so-called Culebra cut which will be a little more than nine miles long with a minimum width at the bottom of 200 feet. The northern end of this cut will be at Bas Obispo at the point where the canal line leaves the valley of the Chagres. A single lock in duplicate at Pedro Miguel will mark the southern or Pacific end of the cut, and through this ships will pass to a lower lake, 55 feet above mean tide, in which they will proceed to the two locks at La Boca, and there descend directly to a dredged channel in the bay of Panama.

Actual dry excavation is only required at the various lock sites, in the Culebra cut, and, to a minor degree, for the last few miles of the course through the Chagres valley north of the Cut.

THE CULEBRA CUT.

Recent exposures and borings in the central region supply definite knowledge as to the nature of the materials to be encountered in excavating the prism between Bas Obispo and Pedro Miguel. It will be seen from the geological profile that between Bas Obispo and Empire excavation will be entirely in the early andesitic breccias, the layer of superficial red clay and

decomposed rock having been passed. From near Empire southward the cutting will be in the soft shales and sandstones that may be referred to as the Culebra beds. It has been impossible to discover the character of the contact between these beds and the breccias that belong to what has been called the Obispo formation. The fact that limestones of the upper part of the Culebra beds are found at many points as far north as Las Cascades resting on the Obispo rocks indicates an unconformity rather than a structural break. Several small faults do occur in the Culebra beds between Culebra and Empire, crossing the canal in an east-west direction, but they will have no effect on excavation nor upon the stability of the slopes. With increased depth there will be little change in the hardness of the Culebra beds; they may be classified as soft rock and should be easily handled by steam shovels to the desired depth if broken up by blasting. About half of the excavation in the Cut between Bas Obispo and Pedro Miguel will be in these comparatively soft Culebra beds and the rest in the hard andesitic breccias.

The physical character of the Culebra beds, consisting as they do of alternating layers of sandstone and shale, is peculiarly favorable to landslides. Structurally, however, the strata are so nearly horizontal or have such low southerly dips north of Cerro Culebra, or "Gold Hill," as the culminating peak at the pass is called by the Americans, that movements involving large masses of rock are improbable, while slopes of suitable angles will do away with the danger of minor slips.

Gold Hill is bounded on the north and south by faults, the mass of the hill having sunk with respect to the rocks on the other sides of the faults. During the process of faulting the strata were tilted to the east and now have steep dips in that direction. This structure is further complicated by the presence of large masses of basalt that were intruded in the Culebra beds prior to the faulting. The induration resulting from these intrusions has been so extensive that all the rocks in Gold Hill are now very hard and firm, and with the sedimentary beds dipping into the hill the conditions are such that landslides are most unlikely.

The basin south and east of Gold Hill collects large quantities of water during the rainy season, and this escapes in springs along the edge of the cut where landslides have taken place from time to time. The materials involved in these slides are purely superficial; in some instances French spoil-banks have slipped. The cause in all cases seems to be the saturation of the unconsolidated surface material and its movement on layers of slippery clay in the Culebra beds or of residual clays on which spoil was dumped. The slides have not been serious, and although they may continue for a number of years, the removal of the material before it reaches the edge of the cut and the gradual reduction of the slopes back of the cut will stop this trouble. The French attempted to overcome the difficulty by an elaborate system of drainage that has proved entirely inadequate, and it is improbable that any plan of this sort would be practical or economical.

THE DAM AND LOCK SITES AT GATUN.

At Gatun the sides of the broad lower valley of the Chagres converge and the stream passes through a gap a little over one mile wide in a cuesta-like ridge known as the Sierra Quebrancha. These hills trend northeast from Gatun in a well defined chain; on the southwest side of the valley the range widens and extends south and west as a hilly region between the Trinidad drainage and the sea with a divide near the Trinidad River. From Bohio northwest the whole region is one of young sedimentary rocks, and the wide and open character of the Chagres, Trinidad and Gatuncillo valleys is due to the ease with which these rocks have been eroded. Younger and slightly harder rocks have been preserved in the hills bordering the lower part of the valley and it is of these that the Sierra Quebrancha is composed.

The Lock Site.—The site selected for the locks at Gatun is about one quarter of a mile from the Chagres River in the southern extension of the Quebrancha Hills. The rocks of which these hills are composed belong to the Gatun formation of the Oligocene. They are almost entirely fine grained, bluish-

gray, argillaceous sandstones; occasional coarse gritty layers are present, and, at the base, is a conglomerate. A microscopical examination shows that the sandstones are composed of materials derived from the older igneous rocks of the region and consequently contain little or no quartz, but considerable quantities of the ferro-magnesian silicates and feldspar embedded in an earthy and often calcareous matrix. Middle Oligocene fossils are abundant, and at some horizons make up a large part of the rock. Decomposition results in the formation of red and yellow clays indistinguishable from those derived from the original rocks; the depth to which such decomposition extends is variable, but at Gatun fresh rock occurs within 15 feet or less of the surface.

As shown by the accompanying profile, Plate VIII., Fig. 2, in which the position of the center walls is indicated by broken lines, excavation for the locks will be in the fine-grained argillaceous sandstones except at the lowest point to be reached, at the extreme southern end of the upper lock, where the conglomerate near the base of the formation will be encountered. The rocks as a whole are well consolidated and make excellent cores with the diamond drills. When taken out and exposed on the surface they remain firm and hard; in rare instances they have been found to crumble and break down into a sandy clay. The rocks are compact and capable of withstanding pressures many times greater than those to which they will be subjected by the lock walls, but being poorly cemented are unable to resist active erosion and will, of course, have to be fully protected where such action is anticipated.

On account of the very considerable amount of clay present in all of the rocks it is believed that they will prove to be almost entirely impervious to water. The conglomerate is an exception, for although it contains much clay, it has been found where exposed in a test pit at the southern end of the lock site to be water bearing. The flow was not great and none was encountered in passing through the overlying sandstones. As shown in the profile the walls of the locks will rest upon the

sandstones at all points except at the extreme southern end where, for a few feet longitudinally, the foundations for the east and center walls will be on this conglomerate. It is unlikely that any difficulty will be encountered in making the excavation for the locks on account of the flow of water from the conglomerate, while the construction of the bottom of the locks in the form of an inverted arch for a short distance from the upper end will control any water pressure from below after the locks are completed.

In the early records of borings made at the lock and dam site at Gatun the argillaceous sandstones were described as "indurated clay," and this term was used in the report of the Consulting Board. It was originally applied to the solid rock underlying the alluvium that fills the Pleistocene valley of the Chagres. Both the argillaceous sandstone and the alluvium are composed of materials of the same composition, and in passing from one to the other, the harder sandstones were not unnaturally regarded as "hard pan" or "indurated clay." The continued use of the term is unfortunate, and is responsible for not a little of the misunderstanding that exists in regard to the character of the foundations for the locks.

The Dam Site.—The Pleistocene valley of the Chagres has been identified at a number of points between Gatun and Alhajuela by means of borings made in exploring possible sites for dams. At Alhajuela, over 50 miles from the mouth of the river, solid rock occurs about 30 feet below the present stream bed and 60 feet above sea level. In descending the river the depth of the Pleistocene valley increases gradually until at Gatun its bottom is a little more than 300 feet below sea level. With the increase in depth there is also a change in the character of the valley-filling from gravel and coarse sand at Alhajuela to the finest silts and clays at Gatun.

Character of the Pleistocene Alluvium.—In the early stages of a cycle of erosion when streams are flowing in young valleys or canyons, like that of the Chagres, they are heavily charged with detritus. All of the finer part of this material is swept

down to the sea and the coarser is deposited along the upper portions of the streams, but gravels and small boulders may be carried by floods as far down as the mouths of the rivers. If subsidence takes place in the early stages of the cycle, as in the case of the Chagres again, the velocity of the streams is at once checked and they are able to carry only the finest material which is deposited farther and farther back from the mouths as subsidence continues. In other words, one should expect to find at the bottom of such a gorge as that of the Chagres at Gatun a comparatively thin deposit of coarse sand, gravel and a few boulders, while the greater part of the alluvium should consist of clay and silt with a small amount of fine gravel and sand mixed with it. This, indeed, is the case, and it is interesting to note the increase in the proportion of the coarser materials at the different dam sites that have been explored higher up the valley.

The borings through the alluvium were made by the "wash drill" or "water jet" method, and when samples were taken from time to time only the coarse material was collected, the finer being held in suspension and carried off with the water flowing from the holes. This accounts for many of the records specifying "sand and gravel" at points comparatively near the surface, whereas it is most improbable, as has been pointed out, that any sand or gravel, unmixed with clay, occurs in the deposits except at or very near the bottom. When the deep gravel beds are reached by the borings the difference in character between them and the overlying materials is at once evident.

In certain of the holes flows of water were encountered, but after a few hours the flow invariably ceased. Such flows are believed to occur when the bore-holes enter lenticular deposits of water-bearing sand or gravel which, being surrounded by much less pervious material, are in the nature of reservoirs containing water under pressure. When tapped by a boring the water rises to the surface and overflows until the pressures are readjusted. Far from indicating porous materials underlying the site for the dam, the occurrence of such flows of water only

proves the extremely impervious character of the alluvium between the surface and the water-bearing beds. It may be stated with confidence, therefore, that to a depth of a least 200 feet below sea level the deposits filling the Pleistocene valley of the Chagres consists of blue clay or fine silt, sometimes mixed with sand and gravel, and often containing shells or the trunks and branches of trees.

By referring to Plate VIII., Fig. 3, it will be seen that the dam will have rock of the Gatun formation as foundation at each end and near the middle, while at two points, near the eastern and western ends respectively, it will rest on alluvium filling two separate Pleistocene gorges; the one to the right in the diagram is that of the Chagres while the slightly shallower valley to the left probably represents the Pleistocene channel of the Gatuncillo, at present an important tributary of the Chagres, entering that river just above Gatun. It is interesting to note that the Chagres is now superimposed on the alluvium filling the Pleistocene valley of the Gatuncillo.

A diversion channel, through which the Chagres will flow during the construction of the dam, will be cut in the high ground that rises about half way between the eastern and western ends of the dam. East and west of this temporary spillway extending to either side of the valley will be the great earth embankments, which, when completed, will have a width of 100 feet at the top; at the level of the lake the distance through the dam will be 374 feet, according to the plans of the Consulting Board, and at sea level the distance will be one half mile, making a cross section of unusual magnitude. Up to the level of the lake the dam will be built of material dredged from the canal between the Gatun locks and Limon Bay and pumped by suction dredges into the dam. In this way it will be possible to separate the coarse and fine materials composing the alluvium, depositing the coarser toward the downstream slopes and forcing the finer material into the upstream portion of the dam.

The safety of such a dam is beyond question, and the impervious character of the foundation upon which it is to be built can not be doubted.

THE LOCK SITE AT PEDRO MIGUEL.

The rocks of the lock site at Pedro Miguel are similar to those of the Gatun formation, but they are geologically older and belong to the same series of beds as the sedimentary rocks of the Culebra Cut. Although the Culebra beds are as a whole variable in texture, those in which excavation for the locks at Pedro Miguel will be made are remarkably uniform. They consist of well-bedded sandy shales, containing plant remains in a few places, and at some horizons lenticular masses of concretionary limestone are common. The physical properties of the rocks differ somewhat from those of the rocks at Gatun; being more argillaceous the shales are naturally less permeable to water, and experience in sinking test-pits showed that they were very tough and required more blasting than did the Gatun rocks under similar conditions. This greater toughness is to be attributed to the argillaceous nature of the rock; for the same reason the compressive strength is probably slightly less than that of the more sandy rock at Gatun.

In the vicinity of Pedro Miguel the Culebra beds have a prevailing dip of five to ten degrees to the southeast varied by sharp local folding; moderate fracturing has accompanied the folding, and slickensides are shown at many points where exposures have been made by recent excavation.

At the point where it is proposed to construct the lower gates a dike of augite-andesite crosses the lock site in a direction slightly east of north. It has a width of about thirty feet where exposed on the southwest side of the cut and its contacts with the shales are sharp and clean. On the northeast side of the cut the dike turns to the north and the contact is more irregular, small apophyses having been thrown off into the shales. The folding and dislocation of the Culebra beds at this point are due to some extent to the intrusion of the dike but it is itself also fractured, and slickensided surfaces in its mass and in the shales adjacent to it indicate that minor faulting or shearing has taken place subsequent to intrusion.

These structural features have a direct bearing on the character

of the foundations. The dike, on account of its shattered condition that borings have shown to exist below the lowest points to be reached in excavation for foundations, will be permeable to water. The shales also have been made more or less pervious as a result of their deformation and consequent fracturing. Local seepage of surface water is, therefore, to be anticipated, but the character of the Culebra beds northward is such that no flow of water is likely to occur through them even when the canal in the summit region is filled with water.

The difference in hardness between the andesite of the dike and the much softer shales of the Culebra beds will require special consideration in planning the locks since an unequal settling of the walls is not unlikely to occur. Furthermore the possibility of even very slight differential movements in the zone of fracturing and dislocation in the dike and shales must be taken into account. By the construction of the lock walls in sections the danger of injury to monilithic walls as a result of such movements should be avoided.

THE SOSA LOCK SITE.

The foundations for the Sosa locks at the Pacific end of the canal will be on the massive augite-andesite of which Sosa Hill is composed. The rock, although traversed by a complicated system of joint-planes is, wherever it has been observed, extremely massive; it has not been shattered as has the dike at Pedro Miguel, and therefore little or no seepage is to be anticipated. As shown by borings the elevation of the surface of hard rock is variable; a layer of decomposed rock overlies the fresh, and in the region of the tidal flats this is covered by alluvial clays and sands. At all points fresh rock will be found for the lock walls to rest upon.

THE LA BOCA AND SOSA-COROZAL DAM SITES.

The lake at the Pacific end of the canal will be formed by two dams, one across the mouth of the Rio Grande at La Boca extending from Sosa Hill to San Juan Hill, and another from

Sosa Hill to the high ground in the vicinity of Corozal. The Rio Grande Valley will be flooded from La Boca to Pedro Miguel and the surface of this artificial lake will be 55 feet above mean tide.

La Boca Dam.—The ground upon which the dam at La Boca is to be built consists entirely of alluvium resting upon sandy shales, similar to those of the Culebra beds, in the middle of the valley, and at either side on massive igneous rocks. The borings have developed a Pleistocene channel below the present flood-plain of the Rio Grande like that of the Chagres at Gatun, but they have shown that at the point where the dam is to cross the maximum depth is only about 70 feet below mean tide. The alluvium, like that in the upper part of the Pleistocene valley of the Chagres at Gatun consists largely of clay with sand and fine gravel mixed with it at different elevations and will form an entirely impervious foundation for the dam.

Sosa-Corozal Dam.—Material of essentially the same character as that at La Boca underlies the site of the Sosa-Corozal dam, but is of less thickness. The rocks beneath the alluvium at depths of from 30 to 60 feet are sandy shales probably belonging to the Culebra beds. Rhyolite tuffs are exposed in the hills at the northern end of the dam.

The method of constructing both of these dams at the Pacific end of the canal will be essentially the same as that to be employed at Gatun, and in both cases the foundations are safe and impervious.

EARTHQUAKES.

An account of the Isthmian geology and its relation to the canal would not be complete without a discussion of the possibility of the occurrence of earthquakes. Unfortunately there is little reliable information on this subject, and perhaps for this reason those opposed to a lock canal have laid stress upon the likelihood of serious damage to locks and dams as a result of seismic disturbances.

This whole subject has been ably discussed by M. Marcel

Bertrand in a paper published in 1899[1] in which he concludes that Panama is the most stable region and the one least menaced by seismic disturbances in Central America. In the opinion of the present writer our knowledge of the causes of earthquakes is too limited, and too little is actually known of the structure of the region lying between the Atrato River and Lake Nicaragua to warrant such positive statements. It is certain, however, that the canal zone is so far removed from centers of volcanic activity that it can not be affected by any disturbances from such a source, the nearest volcanoes being those in Costa Rica, while volcanism in and near the zone ceased in the Miocene.

Dutton has suggested that past experience is perhaps the most trustworthy guide; regions that have been subjected to severe earthquakes are likely to be affected again, while those that have been free from shocks may reasonably be expected to be unshaken in the future.

Panama has had earthquakes in the past, it is true, but none has been sufficiently violent to damage the many churches and other edifices built of flimsy rubble that have been standing in the city for more than two hundred years. The most violent shock on record occurred in 1882 and threw some of the bridges of the Panama Railroad out of alignment, but beyond this no damage was done. It is improbable that the massive concrete walls of the locks, laid upon solid rock, will be affected by any but shocks of the utmost violence such as have never been recorded in the region. In the writer's opinion greater damage would be likely to occur from landslides, caused by earthquakes, in the deep cut of a sea level canal, than would be sustained by the locks or dams as a result of shocks of the same intensity.

MATERIALS FOR CONSTRUCTION.

As soon as the locks and regulating works are begun, large quantities of materials for making concrete will be required. In addition to millions of barrels of cement many thousand tons

[1] "Les Phénomènes Volcaniques et les Tremblements de Terre de l'Amérique Central," Marcel Bertrand, Paris, 1899.

of crushed stone and sand will be used, and of these there is an ample supply. It is unlikely that any dimension stone will be employed, and no rock adapted to this purpose has been found on the Isthmus.

Rock.—Although the majority of the rocks are much decomposed near the surface, fresh material occurs at a number of places suitable for concrete or other purposes where crushed stone is required. Practically all the available rocks are the basic andesites or basalts that occur in the central and southern portions of the Zone. There are extensive outcrops at Sosa and Paraiso near the sites of the locks at the Pacific end of the canal, but on the Atlantic slope no good rock has been found nearer Gatun than San Pablo. This is a hard rhyolite tuff or breccia, but much better material occurs at Porto Bello, 18 miles east of Colon, where hills of massive andesite rise from the water's edge in the harbor, making it possible to load the crushed stone on scows and transport it directly to Gatun.

Sand.—No good sand for use in mortar or concrete has been found near the points where such material will be required. Some of a fair quality, occurring at a number of places in the Chagres River between Gamboa and Bohio, could be used if necessary, but it is mixed with gravel and the bars are completely covered during the rainy season. About eight per cent. of earthy or clayey matter is present in this sand but not in sufficient quantities to be harmful.

An abundance of a very high grade of sand containing over eighty per cent. sharp, glassy quartz occurs on the beach at Chorrera 18 miles west of La Boca on the Pacific coast, and on the Atlantic side deposits of sand, derived from basic rocks and containing little or no quartz, have been found just east of the harbor of Porto Bello. Although not of as high grade as the Chorrera sand this material will be, it is believed, entirely satisfactory for use in making the concrete at Gatun.

CEMENT.

The distance from the source of supply and the relatively high cost of the manufactured article brought from the United States, England, or Germany have made it desirable that raw cement materials be found on the Isthmus.

Up to the time of the writer's first visit to the Canal Zone in the summer of 1906 some search had been made for a "cement rock" but without satisfactory results. After a general study of the region it was evident that none of the materials ordinarily used in the manufacture of Portland cement were available in sufficient quantity, and it became necessary to look to new sources for the lime and clay.

Limestones in abundance occur high up the Chagres River in the vicinity of Alhajuela but they are very inaccessible and of poor quality; the only other known deposits are those found near Empire and they are too small and too variable in composition to be considered. Residual clays are everywhere but they contain grit and partly decomposed fragments of rock, while the finer shales of the Culebra beds, otherwise satisfactory, are more than 30 miles from the nearest lime deposits.

Coral reefs occur everywhere along the Caribbean coast, and for the lime it was decided to experiment with this material which may be obtained easily and cheaply.

After dredging was abandoned by the French in the canal and diversions near Colon these channels rapidly filled with clay brought down by the Chagres. Examinations made at a number of points have shown that the physical and chemical composition of this clay is extremely uniform, that the supply is practically inexhaustible, and that the cost of excavation by dredging is very low. The proximity of these clays to the coral is also a decided advantage. It was feared, however, that these alluvial clays might be a little too low in silica to make a thoroughly slow-setting cement, so samples of a pumiceous rhyolite tuff occurring between San Pablo and Tabernilla were also selected for experimental tests.

A number of barrels of these materials were shipped to the

United States and three burning tests made: one of coral and clay; one of coral and rhyolite; and one of clay and tuff combined with the coral as a base.

Analyses of the raw materials and of the clinker, made at a testing laboratory in the Lehigh district, are as follows:

ANALYSES OF CEMENT MATERIALS.

	I.	II.	III.	IV.	V.	VI.
SiO_2	0.89	49.91	60.93	21.08	22.83	22.75
Fe_2O_3	0.36	10.06	5.46	4.64	2.87	3.67
Al_2O_3	0.32	15.48	15.86	6.73	6.32	6.42
CaO	52.62	6.98	4.02	63.60	64.32	64.57
MgO	0.38	2.27	1.79	1.60	1.58	1.58
SO_3	—	—	—	1.06	0.34	—
Loss on ignition	43.50	12.92	10.44	—	—	—

I., Coral, Limon Bay. II., Clay, Boca Mindi. III., Rhyolite tuff, San Pablo. IV., Clinker, coral and clay. V., Clinker, coral and tuff. VI., Clinker, coral, clay and tuff.

It will be seen from these analyses that the coral is a remarkably pure lime carbonate low in magnesia. The clays, although low in silica, contain more iron in proportion to the alumina than most of the argillaceous materials used in the United States, and for this reason it is believed that, in combination with the coral, they may make a cement better able to resist the destructive action of sea water than the ordinary Portland cements. The composition of the rhyolite tuff is about the same as that of many clays or shales used in this country.

The three different clinkers are so uniform in their chemical composition that it is of interest to compare the physical tests of the cements made from them. The specific gravities were, for the coral-clay cement: 3.23; for the coral-tuff: 3.20; and for the coral-clay-tuff combination: 3.17. The fineness of the ground cement is given in the following table:

FINENESS OF GROUND CEMENT.

	No. 50 Sieve. Per Cent.	No. 100 Sieve. Per Cent.	No. 200 Sieve. Per Cent.
Coral-clay	100.0	98.0	90.3
Coral-tuff	100.0	99.0	93.3
Coral-clay-tuff	100.0	95.0	88.6

The setting time of the coral-tuff cement was rather quick but the addition of 2 per cent. of plaster to this and the other cements brought them up to the standard in all cases.

The average tensile strength of briquettes (in pounds per square inch) is given below:

TENSILE STRENGTH OF BRIQUETTES.

Neat.

	24 Hours.	7 Days.	28 Days.	3 Months.	6 Months.
Coral-clay	237	633	719	735	822
Coral-tuff	210	561	635	623	678
Coral-clay-tuff	288	613	734	677	—
Sand (3:1).					
Coral-clay		205	301	365	394
Coral-tuff		227	312	392	427
Coral-clay-tuff		173	302	319	—

The slightly lower neat strength of the coral-tuff cement is doubtless due to the finer grinding of this clinker, but on the whole the tests have given remarkably uniform results, the differences being no greater than one would expect to find in three separate tests of a single brand of commercial cement. If one may judge from such slight variations, the coral-clay cement makes the best showing with the neat briquettes, while a stronger sand mortar is made with the coral-tuff cement.

Without going further into details, it may be said that the records of each test are as high or higher than those of standard commercial brands of Portland cement made in the United States or Europe, and consequently the choice of the raw materials to be used depends largely upon their first cost. From this point of view there is a decided advantage in favor of the coral-clay cement, the clay being easily and cheaply obtained by dredging close to the points where the coral-reefs may be most advantageously worked. About the only objection to the use of the clay would be the necessity of drying, which might be accomplished in part in air by the accumulation of stock piles under cover. It is quite possible that a wet process might be found

more economical than the dry method now generally used.

Estimates have shown that the amount of raw material available in the immediate vicinity of Colon is far beyond that required for twice the number of barrels of cement to be used in completing the canal, and that the cost per barrel would be considerably below the price now paid for cement brought from the United States.

FUEL.

Thin seams of a low grade lignite are not uncommon in the clays and shales of the Culebra beds exposed in the cut, and traces have been found at a number of other places on the isthmus, but as yet no workable deposit has been discovered. Even if large deposits existed it is improbable that the lignite would be satisfactory as a fuel, and comparing costs and efficiency there would be little or no advantage in using it instead of good coal from the United States.

CONCLUSION.

In conclusion it may be said, that of the many problems the engineers have had to meet, those in which geology has played an important part are now well understood, and do not present the difficulties that in the early days of the project seemed almost insurmountable. This knowledge has come gradually, and with it, it is believed, an increasing respect on the part of engineers for the aid that the science of geology may sometimes offer them in their work. There can be no doubt that, had as thorough a geological study been made of the Panama region at the time the Americans assumed control, as was made of the Nicaraguan route, much of the discussion in regard to the feasibility of the dam at Gatun, and of the lock type of canal in general, would have been avoided.

WERE THE APPALACHIAN AND EASTERN INTERIOR COAL FIELDS EVER CONNECTED?[1]

GEORGE H. ASHLEY.

Were the Appalachian and Eastern Interior Coal Fields ever connected? There are probably very few men interested in coal-mining to whom a close scrutiny of a coal map of the eastern United States has not suggested this interesting question. By the earlier geologists the former continuity of the two fields was assumed without question and the Pennsylvania names of sandstones were often applied to the sandstones in Illinois, Indiana, and Kentucky. The fact that the two fields are separated by little more than 65 miles in central Kentucky, and that this gap is over the arch of the Cincinnati anticline, the crest of which has been removed during successive periods of peneplanation, gives color to such an assumption. Again, a comparison of the western edge of the Appalachian field in Kentucky with the eastern edge of the Illinois field discloses many points of resemblance.

In northeastern Kentucky the western edge of the coal field consists mainly of a massive sandstone comprising one or two members, with two or three coal beds of small importance. Similar massive sandstones of about the same thickness make up most of the coal measures along the eastern edge of the Illinois field in Indiana, and a comparison of their fossils indicates that they are approximately of the same age. The massive sandstone so prominent at the western edge of the Appalachian field, where crossed by the Louisville Division of the Chesapeake and Ohio Railroad, is correlated by David White as Sharon, and fossils from the sandstone of Orange County, Indiana, on the eastern edge of the western field are classed as "not younger than Sharon."

So too, the miner going from work in the Pittsburg coal

[1] Published by permission of the Director of the U. S. Geological Survey.

field has thought he found resemblances between the Pittsburg bed and Coal VI. of Sullivan County and elsewhere in Indiana. Leaving out of account the Pittsburg roof coal, which might be considered to have its counterpart in Coal VIa of Indiana, the "rider" of Coal VI., the two coals have the same number of partings similarly placed. Each has an upper bench; in Indiana at the Hymera mine in Sullivan County this has a thickness of 30 inches, in the Pittsburg bed it is termed the breast and at the Ormsby mine of Pittsburg it is 33 inches. Then comes the "bearing in," 4 inches at Ormsby, 6 inches at Hymera; then the brick coal at Ormsby, 10 inches; the main coal at Hymera, 34 inches; the bottom coal at Ormsby 14 inches with 12 inches at Hymera, in both cases poor and left as a floor. Such incidental resemblances, which are not uncommon, have often led to hastily formed conclusions.

There is still another strong resemblance in the manner of deposition of the coals of the two fields, in that the lowest beds of each were deposited in very limited channels or lagoon-like basins, while the upper coals became more regular and more extensive.

To answer the question regarding a possible former continuity, it is necessary to examine the fields more broadly. It will be convenient to study the problem in two parts, the first relating to the rocks of Pottsville age and the second to conditions in post-Pottsville time. In considering the Pottsville, it is well to recall the conditions existing in the Appalachian province in Pottsville time. The work of David White and others has shown conclusively that the earlier or lower Pottsville was deposited only in a trough, along what is now the extreme eastern edge of that coal field, the western part of the field at that time being dry land. With the progress of time a movement of subsidence probably allowed conditions favorable for the formation of coal and the deposition of sediments to gradually spread westward, so that while the lowest or oldest beds are confined to the eastern side of the field, the higher beds extend further and further westward, until in Sharon time practically the whole of the present coal field, except portions of Pennsylvania, as included in the area of coal

formation. From the standpoint of our present inquiry it is of special interest to note that in Ohio and at least northeastern Kentucky the present limits of the coal field were not reached until practically Sharon time, the Sharon sandstone there lying on the Lower Carboniferous limestone. If future studies show these conditions to hold all along the western edge of the Appalachian field it is evident that if any rocks of Pottsville age older than Sharon exist in the Illinois field, they were not connected with the pre-Sharon rocks of the eastern field, but were laid down in a distinct basin where the Illinois field now lies. According to the correlations make by Professor Crandall and others in Kentucky, the western edge of the eastern coal measures showed a steady increase of thickness going southwestward, so that as one approaches the Cumberland River, where the eastern field comes nearest to the western field to-day, there are 300 feet of sandstone, shales, and as many as 10 coals below what they correlate as the Sharon. The Sharon coal as recently identified by David White in northeastern Kentucky is somewhat lower than that so-named by Mr. Crandall. So it seems likely that not all of this thickness may prove to underlie the Sharon in the southwestern part of the eastern Kentucky coal field.

Along the eastern edge of the Illinois field, as stated, the known Pottsville strata comprise a thickness of 100 to 200 feet of rocks, mostly massive sandstone, known as the Mansfield sandstone. After studying a collection of fossils from this sandstone from Orange County, Indiana, Mr. White expresses the opinion that, while they are certainly not later than the Sharon, they show the closest affinities with the fossils of his Horsepen group of West Virginia, which is of practically the same age as the Quinnemont coal of New River. Now on New River the Quinnemont coal lies fully 1,000 feet below the position assigned by Mr. White to the Sharon coal. Therefore, while there is much general resemblance between the coal measure rocks along the western edge of the eastern field and the eastern edge of the western field, if later work by Mr. White bears out his first suggestion, it would appear probable that the recognized Pottsville

rocks of the eastern edge of the eastern interior field are the older and were therefore laid down in a separate and disconnected basin.

While the later or post-Sharon rocks of Pottsville age are not usually found along the extreme western edge of the Appalachian basin, the evidence seems fairly clear that their absence is due to erosion. In the Appalachian basin the evidence seems good that these later rocks were everywhere laid down regularly upon the pre-Sharon rocks, with only such irregularities as are common all through the coal measures. In the Illinois basin, on the contrary, the laying down of the sandstone of Quinnemont age appears to have been followed by uplift that raised these rocks above the level of deposition and reduced the area of the coal field to well within the present limits. That deposition of coals, sandstones, and shales may have continued in the center of this bowl-shaped basin with little or no interruption is quite likely, but the changing land levels apparently did not permit this deposition to reach out to the present eastern borders of the coal field until some time later, certainly not at the northeast and probably not at the east. At the north in Indiana it appears probable that the border of the coal field was not reached by the gradually spreading coal deposition until well into post-Pottsvile time, though coals of late Pottsville age are found in northwestern Illinois. Fossils associated with the coal which in northern Indiana lies just above the Mansfield sandstone have been determined by White as Lower Conemaugh. Further south, lower coals reach the edge of the coal field, so that, along the Ohio River, it is possible that the lowest coals, lying just above the Mansfield, may by of Pottsville age. However, in view of the physiographic conditions just described, the evidence is rather against than for their having extended eastward far enough to have connected with the later Pottsville rocks of the Appalachian field.

As regards the rocks of post-Pottsville age the case seems to be clearer. In the first place, these rocks on the basis of their coal contents are divided in Pennsylvania, Ohio, and eastern Kentucky into four divisions which have long been known as (1) the Dunkard or upper barren measures, (2) the Mononga-

hela or upper productive measures, (3) the Conemaugh or lower barren measures, and (4) the Allegheny or lower productive measures. The Conemaugh with a thickness of 600 feet contains practically no commercial coal, though it has many thin coal beds, several of which at one or two points are supplying coal for shipment. In Indiana and western Kentucky no such division into two well-separated groups is found, the coals there being about equally spaced—with the important seams seldom more than 100 feet apart.

Furthermore, while it is possible to find many local resemblances between detached features of the two coal fields, a careful comparison of the succession of coals, clays, limestones, iron ores, and sandstones shows that the two columnar sections, as a whole, cannot be matched. If the coals be arbitrarily tied across, the other rocks will not match, even allowing an extreme variation in intervals from one section to the other. Again, detailed tracing of beds in both fields shows clearly that even within the limit of its own field there is hardly a rock or coal bed which cannot be traced to a place where it thins out. Later correlations have shown that this is especially true of the sandstones, while the large amount of diamond drilling of recent years has shown that coal beds, long supposed to be continuous, actually overlap at different horizons. Hence in a general way recent work has tended to emphasize the variability rather than the regularity of the coal measures.

Still more important differences appear if we look more closely at the rocks accompanying the coals. In the first place, the red shale, which is so characteristic of the barren coal measures of the eastern field, is entirely lacking in the western field. However, it may be argued that this was mostly derived from the east and that the supply was not sufficient to carry so far west. Opposed to that argument is the fact that in central Pennsylvania the lower barren measures are almost or quite lacking in red shale, while to the west the red shale not only appears in that formation but seems to increase in thickness until in northeastern Kentucky it not only makes up a large part of the Conemaugh but extends half way down through the Allegheny or the lower

productive measures. In the second place, the limestones, iron ores, and some of the associated rocks tell of very different physiographic conditions in the two fields. It is a singular fact that in the Appalachian basin the majority of the limestones underlie the nearest of the associated coals, as note the Vanport, the Johnstown cement, Upper and Lower Freeport, Pittsburg, and other limestones, all of which closely underlie the corresponding coals; while in the Illinois basin the limestones usually overlie the associated coals. When these rocks are examined more closely other differences come to light. In the Appalachian basin it may almost be termed a habit of the limestones to carry an overlying bed of iron ore, the Vanport or old "ferruginous" limestone being a well-known example. This characteristic is rather strikingly brought out in the old "Hanging Rock" district of Ohio and northeastern Kentucky where four or more such ore-bearing limestones occur. This association does not appear to be accidental, the relation in most cases being so intimate as to give some ground for the hypothesis that the bed of iron is the result of secondary concentration due to the removal of originally highly ferruginous limestone by surface waters. The iron ores of the eastern interior field, on the other hand, occur as ferruginous nodules, often sandy, usually occurring in shales. Again, while the limestones in the Allegheny and lower half of the Conemaugh contain marine forms which are sometimes abundant, as in the Ames or old "crinoidal" limestone, the upper limestones appear to be almost devoid of organic remains and those found have their affinities with the fresh water shells of to-day. In contrast with this, the Illinois limestones retain their sea fauna up to the top. Still further, in the Illinois field in most cases there occurs between the coal and the limestone a peculiar form of shale. I have never seen it in Pennsylvania nor typically developed elsewhere in the Appalachian province. It is commonly referred to as black sheety shale. It is a highly carbonaceous shale with two well-marked characteristics. One of these is a tendency to split along the bed in thin sheets of large size—sheets as large as a wagon bed and one-eighth inch thick often readily splitting out. These sheets when separated

tend to curl in the sun. The other is the presence of a fauna comprised largely of the nautiloids, orthocera and other forms usually considered as belonging to the open sea.

My interpretation of these facts is as follows:

The limestones of the Appalachian field I ascribe largely to the action of plants and bacteria, their accumulation being in bogs or inclosed waters by secretion of lime from the water, as is being done to-day in the lakes and marshes of northern Indiana, Ohio, and southern Michigan. The iron ores were accumulated under similar conditions by the same or associated bacteria in the same way that bog ores are accumulating to-day in the localities named and in many parts of the world. These accumulations were followed by the growth of a peaty deposit that later became coal. In general, the associated coal, limestone, and iron ores accumulated under physical and faunal conditions similar to those under which like deposits are being laid down to-day in southern Michigan, though doubtless amid very different physiographic circumstances.

On the other hand, in Illinois, I conclude that the close of a coal-making period was followed by a slight but broad depression which allowed a sudden incursion of the adjacent sea to bring in open sea forms, while the waves agitated the top of the underlying depressed vegetable deposit, only to lay it down again, with an admixture of mud, as the black sheety shale. Gradually the percentage of mud increased, the deposit became less carbonaceous, brachiopods and other slow-moving forms become more and more abundant until their remains helped at least to make the beds of limestone, which in most cases overlie this black shale.

The conclusions reached may be summarized as follows:

1. The lower or earliest Pottsville of the Appalachian field appears to be definitely absent from the Illinois field, so far as revealed by the exposed rocks.

2. The middle Pottsville, comprising on New River the rocks between the Quinnemont and the position of the Sharon coal, is represented in the eastern interior field and it is possible that the two basins were connected at this time, but the evidence sug-

gests that rocks of this age, as developed in Indiana, are probably slightly older than the westernmost members of the eastern field and representing members that were overlapped in Ohio and Kentucky. If so, they were in all probability deposited in a separate basin.

3. No rocks corresponding in age to the post-Sharon Pottsville in Ohio and Kentucky have yet been recognized on the eastern edge of the Illinois basin. That they may exist hidden in the center of the basins seems not unlikely. During their deposition in Ohio and Kentucky the eastern edge of the western field in Indiana and Kentucky seems to have been lifted above the level of deposition, a fact that renders the union of the two fields at that time very improbable.

4. A comparison of detailed sections of post-Pottsville rocks of the two fields shows an entire lack of agreement not only in detail but in the broader arrangement of the coals and their accompanying rocks.

5. Certain characteristics previously described indicate marked physiographic differences existing in the two basins which, aside from all other considerations, strongly suggest that the two basins during post-Pottsville time were entirely distinct.

THE ASSOCIATION OF ALUNITE WITH GOLD IN THE GOLDFIELD DISTRICT, NEVADA.[1]

FREDERICK LESLIE RANSOME.

INTRODUCTION.

Alunite, a hydrous sulphate of potassium and aluminium with the formula $K_2O.3Al_2O_3.4SO_3.6H_2O$, is one of those minerals the apparent rarity of which is probably due in no small measure to inconspicuousness. The material was first noted at Tolfa, near Rome, where it was used as early as the fifteenth century for the manufacture of potassium alum ($K_2O.Al_2O_3.4SO_3.24H_2O$).[2] This salt, containing 2 parts less of Al_2O_3 with 18 parts more of water, is obtained from the alunite by roasting and lixiviation. Alunite is found also on some of islands of the Grecian Archipelago, near Muszay in Hungary, on Mount Dore in France and in a few other localities in Europe, as well as with the opal of Queretaro, in Mexico. In the United States it has been described in the Rosita Hills,[3] on Calico Peak near Rico,[4] in the National Belle Mine near Silverton,[5] and at Cripple Creek,[6] all in Colo-

[1] Published with the permission of the Director of the U. S. Geological Survey.

[2] For the latest account of this celebrated locality, with a bibliography, see L. De Launay, "La Métallogénie de l'Italie." Tenth Geological Congress, Mexico, 1906, pp. 125–132.

[3] Cross, Whitman, "Geology of Silver Cliff and the Rosita Hills, Colorado." 17th Ann. Rept. U. S. Geol. Survey, Pt. 2, 1896, pp. 52–56. Also *Am. Jour. Sci.*, 3d ser., vol. 41, 1891, pp. 466–475.

[4] Cross and Spencer. "The Geology of the Rico Mountains, Colorado." 21st Ann. Rept. U. S. Geol. Survey, Pt. 2, 1900, pp. 92–94.

[5] Hurlbut, E. B. "On Alunite from Red Mountain, Ouray County, Colo." *Am. Jour. Sci.*, 3d ser., vol. 48, 1894, pp. 130–131. Also Ransome, F. L. "A Report on the economic geology of the Silverton Quadrangle, Colorado." Bull. U. S. Geol. Survey No. 182, 1901, p. 235.

[6] Lindgren and Ransome. "Geology and Gold Deposits of the Cripple Creek District, Colorado." Profess. Paper U. S. Geol. Survey No. 54, 1906, p. 125.

rado. It occurs also at Tres Cerritos, Mariposa County, California.[1]

Mr. W. Lindgren[2] found alunite in the Ryerson mine near Morenci, Arizona, associated with pyrite and kaolin. He regarded it (page 193) as formed by the attack of descending sulphuric acid solutions upon sericite away from free oxygen.

Until recently geologists have regarded alunite as formed exclusively by the attack of sulphurous fumarolic vapors upon feldspatchic rocks.[3] At Cripple Creek, however, the mineral was found only in the oxidized ore, and, like the kaolinite of that district, is probably secondary with reference to the original telluride ores. De Launay,[4] moreover, has recently maintained with cogency that the alunite of Tolfa is probably not, as formerly supposed, a solfataric product, but is due to the action of percolating surface water, charged with sulphuric acid by the oxidation of pyrite, upon a particularly feldspathic facies of the trachyte. It is accordingly no longer justifiable to regard the occurrence of alunite as proof of former fumarolic activity. The mineral may form under very different sets of conditions and it is necessary, in seeking the explanation of any occurrence of it, to keep alternative hypotheses in mind.

In all four of the Colorado localities the alunite occurs in regions which contain ore deposits. In the Rosita Hills and in the Rico and Silverton districts it is apparently not a product of superficial oxidation. No close kinship between this mineral and the ores, however, has been shown, although it was doubtless recognized by all the workers in those districts that there might be some genetic relation between the metallic sulphides and the volcanism of which the sporadic solfataric metamorphism of feldspathic rocks to quartz-alunite aggregates was one manifestation. It is worth noting in this connection that the indexes of

[1] Turner, H. W. "Rocks and Minerals from California." *Am. Jour. Sci.*, 4th ser., vol. 5, 1898, pp. 424–426.

[2] "The Copper Deposits of the Clifton-Morenci District, Arizona." Profess. Paper U. S. Geol. Survey No. 43, 1905, pp. 119–120, 169 and 193–194.

[3] Iddings, J. P. "Rock Minerals." New York, 1906, p. 476.

[4] *Op. cit.*

two of the best and most recent works[1] on ore deposits contain no reference to alunite, showing that the mineral has not been commonly recognized as one intimately associated with ores. Neither is it mentioned, so far as I am aware, in President C. R. Van Hise's work on metamorphism.[1] Professor J. H. L. Vogt,[2] however, in discussing metasomatic vein-processes, has remarked: "I would mention also the formation of alum-stone; quartz-alunite rocks; quartz-diaspore rocks, etc.; and also the formation of bauxites, etc. But I do not know that these changes have been anywhere observed in genetic relation with ore-veins."

In the Goldfield district alunite is so abundant and so generally associated with the intense alteration accompanying ore deposition that it must be looked upon as one of the most characteristic minerals of the gold deposits. This close association of the gold with a mineral which apparently had not been recognized in Nevada prior to the present investigation and which has been reported in comparatively few localities elsewhere, seems worthy of some description, especially as the relation promises to throw light upon the origin of the ores.

ROCKS OF THE DISTRICT.

For a preliminary account of the geology of Goldfield the reader is referred to an earlier publication.[3] A full description of the geology and ore deposits is in preparation and will appear as one of the professional papers of the U. S. Geological Survey. It is sufficient in this place to state that the ores occur in middle or early Tertiary rhyolite, latite, andesite and dacite. Nearly all of these are extrusive flows, but the dacite, which contains most of the important mines, is an intrusive sheet, although the intrusion probably took place beneath a cover of volcanic rocks which

[1] Beck, Richard. "Lehre von den Erzlagerstätten." Berlin, 1901. Stelzner-Bergeat. "Die Erzlagerstätten." Leipzig, 1904–1906.

[1] "A Treatise on Metamorphism." Monog. U. S. Geol. Survey No. 47, 1904.

[2] "Problems in the Geology of Ore Deposits." *Trans Amer. Inst. Mining Engineers*, vol. 31, 1902, p. 150.

[3] Ransome, F. L. "Preliminary Account of Goldfield, Bullfrog, and Other Mining Districts in Southern Nevada." Bull. U. S. Geol. Survey No. 303, 1907.

was not of great thickness. The ore-bearing rocks rest upon, or cut through, a pre-Tertiary foundation of granitic rock with which is involved some Cambrian shale, and are themselves, in outlying parts of the district, unconformably overlain by tuffaceous lake sediments and later Tertiary lavas.

Although comparatively unaltered representatives of most of the rocks named may be found within the district, yet the metamorphism which they have undergone over much of the area is of a most conspicuous kind. Dark pyroxene-andesites, dacite, and rhyolite have alike been changed to nearly white aggregates of secondary minerals. Such products, as a rule, retain only traces of the original textures of the igneous rocks from which they have been derived. To detect and interpret these traces requires patient field observation of the progressive stages of alteration, supplemented by microscopical study.

TYPES OF ALTERATION.

Three types or stages of alteration are recognizable. Where the chemical activity has been most intense the rocks have been changed to porous, fine-grained aggregates consisting essentially of quartz. This is the material of which are composed the hundreds of craggy points and ledges which are one of the most characteristic features of the topography of the district. Although most of these ledges, so far as known, contain no ore bodies, yet, until recently, no ore has been found that was not in or alongside such quartz rock. Some of the discoveries made in 1906, however, show that very rich bodies of ore may occur at places where there is no siliceous outcrop.

The second type of alteration is one in which the rock is changed to a comparatively soft, light-colored mass of quartz, kaolinite, alunite and pyrite. At any given locality the boundary between the rocks representing the two kinds of alteration may be fairly sharp; but the proportions of quartz, kaolinite and alunite vary widely, and consequently, over the field at large, gradations in composition and hardness may be found between these two typical metamorphic products. Both types are usually

associated with the ores and are most conspicuously displayed over a belt of country stretching east from Goldfield past Preble Mountain. This mountain, in fact, is composed chiefly of andesite and dacite which have undergone alteration of the kinds described.

The third type of alteration has effected less conspicuous results than the other two and its products are not closely associated with the ores. It consists in the development of calcite, quartz, chlorite, epidote and pyrite at the expense of the original minerals and groundmass and is thus propylitic in character. It is rather sharply marked off from the second type by the presence of calcite and the absence of alunite, these minerals not having yet been observed together in the same specimen.[1] Rocks which have undergone this form of alteration, chiefly andesite, latite and dacite, still retain something of their original color and texture, the principal external sign of change being a greenish tint instead of the usual dark gray of the fresh rock, and a lack of luster in the phenocrysts.

GENERAL OCCURRENCE OF THE ALUNITE.

Attention was first directed to the occurrence of alunite in the district by the finding of small nests, or crystalline aggregates, up to five millimeters in diameter, of a pale pink mineral in a greatly altered nearly white rock exposed on the east shoulder of Vindicator Mountain, about two miles northeast of the town of Goldfield. The rock contains quartz phenocrysts and was probably originally a rhyolite. The microscope shows that the

[1] Since this was written, very finely crystalline calcite, sericite and probably some kaolinite have been found associated with much larger crystals of alunite in an altered rhyolite from the east slope of Vindicator Mountain. The molecular ratio of soda to potash in the alunite, as determined by Dr. Hillebrand, is as 40 to 45. It is possible, however, that the result obtained for potash may be high in consequence of some decomposition of the sericite by the sulphuric acid used to dissolve the alunite.

The occurrence together of alunite and calcite, apparently developed simultaneously, shows that the alteration took place under conditions which did not permit the free escape of carbon dioxide. It is scarcely conceivable, for example, that calcite could form in the presence of sulphuric acid percolating down from an overlying deposit of oxidizing pyrite.

EXPLANATION OF PLATE IX.

FIG. 1. Photomicrograph of thin section of altered dacite (G. 398) from *D* level of the Combination Mine, Goldfield. Magnified 40 diameters. Nicols crossed.

The section shows a characteristic pseudomorphous aggregate of alunite (*A*), and quartz (*Q*) after a labradorite phenocryst. In this case there is an isotropic material (*O*) present which is probably opal. The groundmass is a fine-grained aggregate of quartz, alunite and pyrite, the crystals of the last mineral (black) being in some places grouped in pseudomorphous aggregates after hornblende and biotite.

FIG. 2. Photomicrograph of thin section of altered dacite (G. 634) from the 200-foot level of the Florence Mine, Goldfield. Magnified 40 diameters. Ordinary light.

The section shows rather more alteration than the preceding, little of the original texture of the dacite remaining. Pyrite (black) is abundant and is crystallized with alunite (*A*). The latter mineral exhibits characteristic lath-shaped sections with irregular ends and felty aggregation. It has evidently developed in some places along devious cracks. There is much quartz (*Q*) in the rock but it is for the most part too finely crystalline to appear clearly in the photograph.

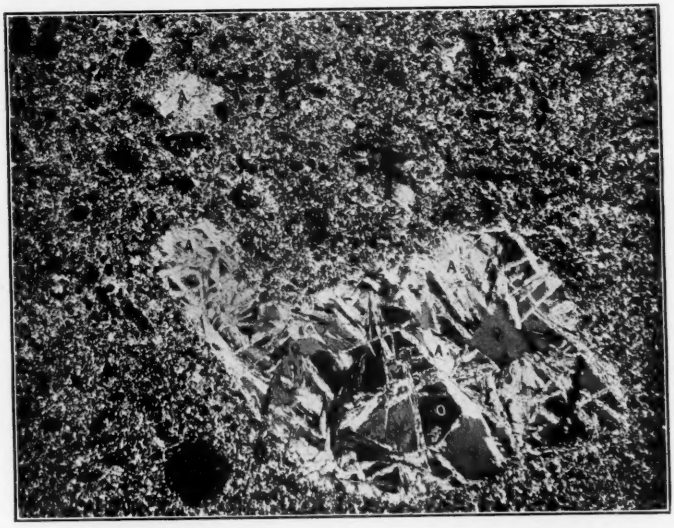

FIG 1.

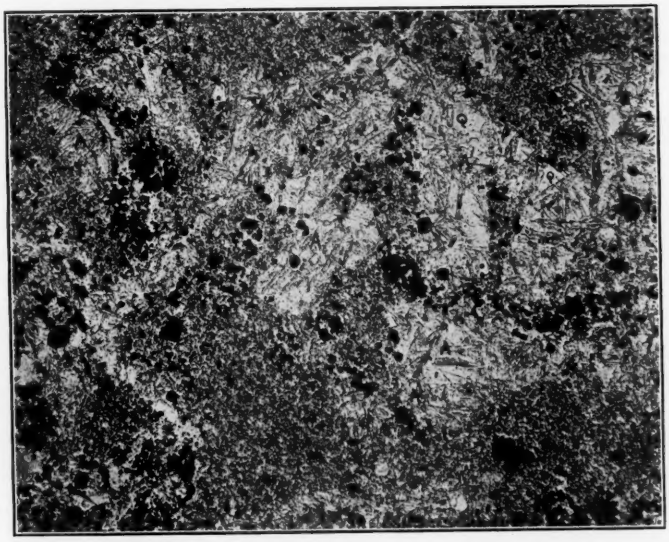

FIG. 2.

feldspar phenocrysts, as well as the groundmass, have been altered to an aggregate of quartz and alunite, the optical determination of the latter mineral being checked by independent chemical tests in the Survey laboratory by Dr. W. F. Hillebrand and Dr. W. T. Schaller. With the alunite is associated a subordinate quantity of an anhedral,[1] colorless mineral of high refractive index, strong birefringence and possessing a single well-marked cleavage. The mineral is biaxial and optically negative, the plane of the optic axes coinciding with the cleavage. It resembles diaspore but differs from that mineral in being optically negative. It has not yet been identified. Undoubted diaspore has been found intergrown with alunite, in the altered dacite of the Florence mine.

Microscopic study of the bleached, altered rocks of the district has revealed alunite in nearly all of them. The rhyolite forming the summit of Columbia Mountain, just north of the towns of Goldfield and Columbia, has been changed to a quartz-alunite rock, the alunite, with some quartz, forming pseudomorphs after the feldspar phenocrysts which probably were originally orthoclase. Alunite is very abundant in the altered andesite and dacite of Preble Mountain and vicinity and is present in practically all of the altered dacite which forms the country rock of the Combination, Florence, January, Red Top, Jumbo and other mines near Goldfield. It also occurs in abundance directly associated with the sulphide ores in these mines, in some places, particularly in the January mine, as a soft, easily pulverized material, of snow white or faint pink color, which is not always distinguishable on mere inspection from certain pure forms of kaolinite which occur in the mines of this and other districts. At Goldfield, the delicate pink tint of the alunite is rather characteristic and serves often as a rough-and-ready means of distinguishing it from the kaolinite with which it is often associated. Close inspection of the altered rocks in which alunite is abundant usually reveals

[1] Anhedral = without crystal faces, xenomorphic, allotriomorphic. See Cross, Iddings, Pirsson and Washington, "The Texture of Igneous Rocks," *Journal of Geology*, vol. 14, 1906, p. 698.

this faint pink color in the aggregates which have replaced the original feldspar.

As a constituent of altered rocks in the Goldfield district, the alunite does not have complete crystal form. It is tabular in habit, the basal pinacoid being well developed and the rhombohedral faces being absent. In thin sections it shows distinct cleavage parallel to the basal planes and parallel extinction with reference to the cleavage. The birefringence is apparently rather stronger than the difference $\gamma - \alpha = 0.018$ given in the table of Lévy and Lacroix,[1] the interference colors in good thin sections being mostly yellow but rising in places to red or blue of the first order. The mineral gives a positive uni-axial interference figure, in sections showing no cleavage. The index of refraction is distinctly higher than the balsam of the slide (1.54), that given for the alunite of Tolfa being $\omega = 1.572$ and $\epsilon = 1.592$.[2] The most decisive optical means of distinguishing the mineral from the optically negative sericite which it resembles in habit and refraction, is by means of the quartz wedge or gypsum plate. Sericite shows the higher interference colors when the section is turned with the cleavage at right angles to the direction of greatest elasticity (X) of the plate or wedge, while alunite shows the brighter colors when the basal cleavage is parallel to this direction.

The soft massive alunite, such as occurs in the January mine, when gently crushed on a microscopical slide and stirred in a drop of water, shows under a high power of the microscope thin, colorless scales of hexagonal outline. The average diameter of those examined is less than 0.05 millimeter, and such is their tenuity that no crystal faces can be recognized on the edges of the basal-pinacoidal scales.

COMPARISON OF FRESH AND ALTERED DACITE.

Inasmuch as the largest and richest ore bodies are in the dacite and as the rock is uniform in character, it was chosen for a close

[1] "Les Minéraux des Roches." Paris, 1888. Also Iddings, J. P. "Rock Minerals." New York and London, 1906.

[2] Iddings, J. P. *Op. cit.*, p. 476.

study of the alteration effected by the ore-depositing agencies. Such comparison is especially favored by the fact that the most intense alteration is often local and consequently it is possible to obtain specimens of fresh and altered rock within moderate distances of each other. The two specimens of dacite analyzed and compared were taken about one and one fourth miles apart.

The unaltered and typical dacite is a dark gray rock with abundant phenocrysts of plagioclase, up to a centimeter in length, lying in a dark aphanitic groundmass. There are present, also, less numerous phenocrysts of augite and biotite with occasional anhedral grains of quartz. The volumetric ratio of phenocrysts to groundmass is estimated at rather less than 1 to 3.

Under the microscope the feldspar phenocrysts prove to be labradorite of the approximate composition Ab_1An_1. They are perfectly fresh, with slightly rounded euhedral[1] outlines. A noticeable feature is the presence in many crystals of closely crowded minute inclusions of glass which in some cases constitute cloudy cores or kernels, in others sharply bounded shells, the center of the crystal being clear. The augite crystals are roughly euhedral or subhedral, with a maximum measured extinction angle, $Z \wedge C$, of about 45°. The biotite occurs in the usual short, rather irregular pseudo-hexagonal prisms. Both biotite and augite are entirely fresh. The quartz phenocrysts are anhedral, with rounded, embayed or sharply angular outlines.

Hornblende is very abundant but is confined almost exclusively to the groundmass, most of the crystals being comparable in size rather with the feldspar microlites than with the phenocrysts just described. The largest hornblende crystal in the thin section studied is about half a millimeter in length. It should be said, however, that in dacite from other parts of the district the hornblende occurs as phenocrysts.

The feldspar microlites in the groundmass are at least in part labradorite of as calcic composition as the phenocrysts. They, the hornblende, and a little magnetite and apatite, are imbedded in an abundant glass, which in transmitted light is gray, with

[1] Euhedral = bounded by crystal faces; idiomorphic, automorphic.

incipient crystals, or crystallites. One crystal of titanite, 0.3 millimeter in length, is in the thin section studied.

A chemical analysis of this rock, made by Mr. George Steiger in the Survey laboratory, is given under I. in the table on page 680.

The arbitrary norm of this rock, calculated from analysis in accordance with the plan of the "quantitative classification,"[1] is as follows:

NORM OF DACITE.

Quartz	17.34
Orthoclase	15.01
Albite	25.68
Anorthite	21.96
Zircon	.37
Diopside	5.21
Enstatite	4.63
Magnetite	4.87
Ilmenite	1.52
Apatite	.34
(Water	2.95)
	99.88

As the rock contains much undifferentiated glass no close calculation of its real mineralogical composition, or *mode,* is possible. The norm and chemical analysis show that the rock is a *tonalose* in the terminology of the quantitative classification.

The altered dacite, of which a chemical analysis by Mr. George Steiger is given under II., was taken from the D level of the Combination Mine, about 235 feet below the surface and in a part of the mine where no apparent oxidation had taken place. The original water level in this mine appears to have been at about 130 feet from the surface, near which depth the oxidized ore gives place to sulphides. The rock analyzed is the typical wall-rock of this and adjacent mines.

[1] Cross, Iddings, Pirsson and Washington. "The Quantitative Classification of Igneous Rocks." Chicago and London, 1903.

For the benefit of the reader who may not have had occasion to familiarize himself with modern petrology it may be explained that the "norm" is a classificatory expedient and is usually very different from the actual mineral composition, or "mode." The dacite for instance really contains no orthoclase, the potassium being combined in biotite and in the glass of the groundmass.

The altered rock is light-gray, flecked with numerous dull white spots which represent the original feldspar phenocrysts. The few quartz phenocrysts are unchanged, but the ferromagnesian, or, more briefly, femic, minerals have wholly disappeared. Pyrite, in small, disseminated crystals, is abundant.

Under the microscope, it is seen that the only original constituents are the quartz phenocrysts, even these showing some development of pyrite along irregular microscopic cracks, and an occasional small crystal of zircon. The feldspars are changed to aggregates of minutely crystalline kaolinite and tabular crystals of alunite, the latter being sometimes arranged in sheaf-like bunches. (See Plate IX.) The alunite has the form characteristic of its occurrence in this district, sections cut at large angles with the basal pinacoid having the shape of narrow laths with irregular ends. The length of these lath-shaped sections rarely exceeds half a millimeter. The alunite, when cursorily examined under a low-power lens, may easily be mistaken for sericite (muscovite), although of course this error is quickly dispelled on closer study, sericite being optically negative and alunite positive. The interference colors, moreover, although bright, particularly in the larger crystals, are of a lower order than those of sericite. Quartz also accompanies the alunite and kaolinite in some of the pseudomorphs after labradorite. (See Plate IX., Fig. 1.)

The former femic constituents can be recognized from the fact that they contain little or no kaolinite, the quartz and alunite being here associated with abundant pyrite. In some cases the pseudomorphous aggregate still preserves a suggestion of the former cleavage of the biotite or of the outlines of hornblende.

The groundmass is changed to a fine-grained aggregate of kaolinite, quartz, alunite and pyrite. The last-named mineral occurs also in irregular microscopic veinlets.

As the rock is wholly crystalline and is made up of minerals of approximately constant composition, it is possible to calculate with some precision the actual mineralogical constitution from the chemical analysis. This, in percentages of mass, is as follows:

MINERALOGICAL COMPOSITION OF ALTERED DACITE.

Quartz (SiO_2)	49.38	per cent. of mass.
Kaolinite ($Al_2O_3.2SiO_2.2H_2O$)	23.99	" "
Alunite[1] ($K_2O.3Al_2O_3.4SO_3.6H_2O$)	15.73	" "
Pyrite (FeS_2)	7.20	" "
Water (H_2O)	2.53	" "
Other constituents	1.17	" "
	100.00	

Compared as they stand, the two analyses show close agreement in silica, alumina, titanic oxide and phosphorous pentoxide. When all the iron in both analyses is calculated as ferrous oxide, that of the altered rock shows a loss of only 0.7 per cent., so that in this respect also the two analyses are very close together. On the other hand, the analysis of the altered rock shows a loss of practically all the lime and magnesia, most of the soda and one half of the potash. It has gained a large quantity of combined water, nearly 6 per cent. of sulphuric anhydride and nearly 4 per cent. of sulphur.

Such a direct comparison of analyses, however, while indicating in this case the general character of the change that has taken place in the dacite, is really a comparison of equal masses of the two rocks, or, more strictly speaking, of the two powders as prepared and weighed for analysis, and as Mr. Lindgren[2] pointed out some years ago, would accurately portray the character of the alteration only under two conditions, namely, (1) that the specific gravity or density of the rock is unchanged by the metamorphism, and (2) that the alteration has not produced any change of volume in the rock mass as a whole, such a change, for example, as takes place when peridotite alters to serpentine. It is essential in an investigation of this kind to determine what materials have been added to or subtracted from a unit volume

[1] The molecular proportions of potash and soda as calculated from analysis II., page 680, are respectively 11 and 14. All of the potash and 8 of the soda molecules are needed to satisfy the 75 molecules of SO_3. Consequently the Goldfield alunite is a soda-bearing variety.

[2] "Metasomatic Processes in Fissure-veins." *Trans. Am. Inst. Mining Eng.*, vol. 30, 1901, pp. 591–595.

(or unit mass) of fresh rock in order to produce a given alteration product.

The changes undergone by a given volume of rock can be determined most simply if the alteration is unaccompanied by swelling or contraction of the whole rock mass. The altered dacite shows no indication of increase of bulk. The field evidence of such swelling would comprise irregular fracturing and squeezing of the rock, the presence of curved slickensided surfaces, and pressure effects in the microscopical texture of the altered dacite. Contraction would probably be more difficult to detect. Any notable degree of shrinkage, however, would be likely to record itself by the development of many irregular open cracks or by some modification of the original texture of the rock, such as the distortion of phenocrysts. Evidence of either kind being absent, it may be concluded with some confidence that whatever volumetric change has taken place is to be sought in a comparison of the porosity of the two rocks and not in change of total bulk.

The porosity of the fresh dacite is exceedingly slight and is not apparent under the microscope. An accurate specific gravity determination of the rock powder used for analysis, made by Mr. George Steiger, gave the figures 2.654.[1] He also determined the specific gravity of the whole hand specimen as 2.63, the difference between the two results being an approximate measure of the porosity. The specific gravity of the altered dacite, which is noticeably porous, as calculated from the mineralogical composition on page 677, assigning to the 1.17 per cent. not accounted for the average specific gravity of the other constituents is 2.769.[2] Determinations by Mr. Steiger gave 2.766 for the powdered rock and 2.49 for the hand specimen. These figures indi-

[1] The specific gravities of the powders were determined by placing weighed quantities in water in a tared picnometer and boiling them at low temperature under reduced pressure. They were then kept for some hours in a thermostat and quickly weighed at 25° C. The specific gravities of the rock masses were obtained by weighing them in air and quickly in water. The figure 2.49, obtained for the altered dacite, is probably slightly too high in consequence of some absorption by pores open to the surface.

[2] The figures used for the specific gravities of the minerals were: Quartz 2.66, kaolinite 2.61, alunite 2.60, and pyrite 5.0.

TABLE SHOWING CHEMICAL ALTERATION OF DACITE.

	I	II	Ia	IIa	Ib	IIb	Ic	IIc	III	IV	V
SiO_2	59.95	60.53	60.86	60.75	161.52	168.04	160.07	151.27	— 8.80	—3.35	— 5.50
Al_2O_3	15.77	15.32	16.01	15.37	42.49	42.52	42.11	38.27	— 3.84	—1.46	— 9.12
Fe_2O_3	3.34	.20	3.39	.20	9.00	.55	8.91	.50	— 8.41	—3.20	— 94.39
FeO	2.34	.14	2.37	.14	6.29	.39	6.23	.35	— 5.88	—2.23	— 94.38
FeS_2	none	7.20	none	7.23	none	20.00	none	18.00	+18.00	+6.84	.....
MgO	2.73	.06	2.77	.06	7.35	.16	7.28	.15	— 7.13	—2.71	— 97.94
CaO	5.84	.41	5.92	.41	15.71	1.14	15.57	1.02	—14.55	—5.53	— 93.45
Na_2O	3.07	.84	3.12	.84	8.28	2.32	8.21	2.09	— 6.12	—2.33	— 74.72
K_2O	2.52	1.06	2.56	1.06	6.79	2.93	6.73	2.64	— 4.09	—1.55	— 60.77
H_2O below 110° C.	.95	1.33	.97	1.33	2.58	3.67	2.55	3.31	+ .76	+ .29	+ 29.80
H_2O above 110° C.	2.00	6.60	2.03	6.62	5.39	18.31	5.34	16.49	+11.15	+4.24	+206.87
TiO_2	.82	.80	.....	.....	.....	.....	.....	.....	.....	.....	.....
ZrO_2	.02	.01	.....	.....	.....	.....	.....	.....	.....	.....	.....
CO_2	none	none	.....	.....	.....	.....	.....	.....	.....	.....	.....
P_2O_5	.26	.27	.....	.....	.....	.....	.....	.....	.....	.....	.....
SO_3	none	5.97	none	5.99	none	16.57	none	14.91	+14.91	+5.67	.....
F	none	trace	.....	.....	.....	.....	.....	.....	.....	.....	.....
MnO	.09	trace	.....	.....	.....	.....	.....	.....	.....	.....	.....
BaO	.11	.06	.....	.....	.....	.....	.....	.....	.....	.....	.....
SrO	.13	not looked for	.....	.....	.....	.....	.....	.....	.....	.....	.....
Totals	99.94	100.80	100.00	100.00	265.40	276.60	263.00	249.00	—14.00	—5.32	

I. Chemical analysis of fresh dacite. George Steiger, analyst. Specific gravity of powder analyzed 2.654. Specific gravity of rock mass 2.63.

II. Chemical analysis of altered dacite. George Steiger, analyst. Specific gravity of powder analyzed 2.766. Specific gravity of rock mass 2.49.

Ia. Analysis I. recalculated to summation of 100, with minor constituents omitted.

IIa. Analysis II. recalculated to summation of 100, with minor constituents omitted.

Ib. Constituents, in grams, in 100 cubic centimeters of fresh dacite free from pores. Specific gravity 2.654.

IIb. Constituents, in grams, in 100 cubic centimeters of altered dacite free from pores. Specific gravity 2.766.

Ic. Constituents, in grams, in 100 cubic centimeters of fresh dacite with 0.9 per cent. pore space. Specific gravity 2.63.

IIc. Constituents, in grams, in 100 cubic centimeters of altered dacite with 9.9 per cent. pore space. Specific gravity 2.49.

III. Gains and losses in grams of each constituent in the alteration of 100 cubic centimeters of dacite to the same volume of altered product.

IV. Gains and losses of each constituent in percentage of mass of the original 100 cubic centimeters of fresh dacite.

V. Gains and losses of each constituent in percentage of its own original mass in 100 cubic centimeters of fresh dacite.

cate that the substance of the altered rock has gained 4.2 per cent. in weight and that, notwithstanding this gain, a given volume of rock, under the supposition of constant volume, has suffered a net loss of 5.3 per cent. in weight consequent upon an increase of porosity.

Since the volume of a given mass of rock, in cubic centimeters, is, for all practical purposes, equal to its weight in grams divided by its specific gravity, the percentage of pore space in the fresh dacite is obtained from the equation

$$\frac{287.4}{2.63} - \frac{287.4}{2.654} = \frac{287.4}{2.63}\, x,$$

where 287.4 is the weight of a specimen of dacite in air, 2.63 the specific gravity of the rock mass, 2.654 the specific gravity of the poreless mineral constituents, and x the proportion of pore space which in this case is equal to 0.9 per cent. In the altered rock, the proportion of pore space is 9.9 per cent., showing an increase in porosity of 9 per cent. of the initial volume.

The chemical changes undergone by the dacite are shown in the accompanying table. Columns I^b. and II^b. are not essential as regards the process illustrated although they represent a step in the reasoning. They are of value also as showing that specific gravity determinations of rock powders, while useful in calculations of the mineral compositions of rocks, are of minor importance in a comparison of this kind, in which it is necessary to know the specific gravity of the mass as a whole, including its pores. Incidentally, it may be remarked that when the specific gravity of a rock is given in connection with its chemical analysis, the method by which the density was determined should be indicated.

In columns I^c. and II^c. are given the number of grams of each constituent in 100 cubic centimeters of each rock, the figures being obtained by multiplying the percentage figures in columns I^a. and II^a. by the respective specific gravities of the fresh and altered dacite. The gains and losses of each constituent are given in grams in column III., and in percentages of total initial

minor constituents omitted.
II^a. Analysis II. recalculated to summation of 100, with minor constituents omitted.
I^b. Constituents, in grams, in 100 cubic centimeters of fresh dacite free from pores. Specific gravity 2.654.
II^b. Constituents, in grams, in 100 cubic centimeters of altered dacite free from pores. Specific gravity 2.766.
volume of altered product.
IV. Gains and losses of each constituent in percentage of mass of the original 100 cubic centimeters of fresh dacite.
V. Gains and losses of each constituent in percentage of its own original mass in 100 cubic centimeters of fresh dacite.

mass in column IV. The last column, V., gives the percentage of loss of each constituent and perhaps most clearly displays the nature of the change.

It appears that the rock has lost a little of its silica, more of its alumina, nearly all of its magnesia and lime, three fourths of its soda and two thirds of its potash. On the other hand, the water has greatly increased, a large amount of sulphuric anhydride has been added and the iron has been converted to pyrite. The iron oxides in column I^{e}. correspond to 11.08 grams of metallic iron, while the pyrite in column II^{e}. corresponds to 8.4 grams of iron and 9.6 grams of sulphur. The quantity of iron originally in the dacite was therefore not only sufficient to form all the pyrite in the altered rock but has suffered a loss of over 27 per cent.

Comparisons of fresh and altered rocks are sometimes made by assuming the constancy of one constituent and recalculating the analysis of the altered rock accordingly. Such a method, in the present case, would give erroneous results.

The metamorphic agent was evidently a strongly acid solution carrying sulphydric and sulphuric acids, and possibly sulphurous acid. Whether the sulphuric acid which was doubtless the direct agent in the formation of the alunite was present in the original solution from the first, or whether it was derived from the hydrogen sulphide, by oxidation at some stage in the movement of the solution toward its point of attack upon the rocks now visible, is an undecided question. The absence of sulphates from contact ore-deposits indicates, however, that oxygenated sulphur compounds are not given off directly from solidifying magmas. The solution was capable of decomposing the silicates in the rocks, carrying part of their constituents away, reacting with the iron of the magnetite and silicates to form pyrite, with the potassium and aluminium to form alunite and with the aluminium to form kaolinite. The large percentage of loss in calcium, potassium and sodium shows that the active solution was far below its saturation point for these elements and was, therefore, entirely different in character from the supposedly alkaline solutions which deposited the large class of sericitic and calcitic gold-

quartz veins[1] exemplified by those of California. Before proceeding farther with genetic considerations I shall briefly describe the mineralogical character of the Goldfield ores.

THE GOLD ORES.

The typical unoxidized ore as it occurs in the dacite near Goldfield consists of pyrite, bismuthinite and a reddish-gray cupriferous mineral having the general composition of tetrahedrite. Native gold is usually associated with these minerals, particularly with the bismuthinite and tetrahedrite, and in the rich ore may be easily visible. These minerals are often arranged in successive layers or crusts around silicified fragments of dacite, the inner crust being usually the richer.

The brownish copper-bearing mineral, here provisionally called tetrahedrite, contains antimony and sulphur, as chemically determined by Dr. W. T. Schaller, and is therefore not bornite, although it goes by that name in the district. It appears so commonly as a constituent of the best ore that there is a strong suggestion that it is auriferous, particularly as the microscope fails in some specimens of reputed rich ore to reveal any free gold. Further investigation of the mineral is in progress. It may possibly prove to be the orthorhombic species famatinite which contains the same constituents as tetrahedrite, but in different proportions, and is characterized by a reddish tint. Bismuthinite, the sulphide of bismuth, is also regarded by the miners as a sign of rich ore.

Concentric shells of ore minerals about greatly altered rock-fragments are rather characteristic of the best ore. Specimens from the Combination mine show an inner zone of free gold and quartz up to an eighth of an inch in thickness. This is covered by a shell of tetrahedrite and this by an outer crust of pyrite. In the Florence mine similar fragments show, first, a shell of pyrite, then one of tetrahedrite, and, finally, a thick crust of quartz speckled with native gold, tetrahedrite and pyrite, and transfixed by needles of bismuthinite. Some of the particles of

[1] See Lindgren, W. "Metasomatic Processes in Fissure Veins." *Trans. Am. Inst. Mining Eng.*, vol. 30, 1901, p. 668.

gold are embedded in the compact quartz, others are inclosed in the bismuthinite. The different crusts are not in every case sharply defined nor are they necessarily continuous.

The native gold of these ores is often in particles so fine and so closely crowded in the gangue that the precious metal resembles a streak of yellow ocher. The proportion of silver is rather small, the average of thirty-four assays of rich ore from the Mohawk mine, made for Mr. J. W. Finch, giving 330 fine ounces of gold and 46.5 ounces of silver to the ton.

Tests and chemical analyses of the ores made for scientific and technical purposes nearly all show a little tellurium, although no tellurium mineral has been recognized in the mines close to Goldfield. Tellurides of gold, not sufficiently well crystallized for a determination of their species, occur in the Jumbo Extension and Goldfield-Belmont mines, near Diamondfield, about four miles northeast of Goldfield, and both tellurite and emmonsite (or durdenite) are found in the oxidized ore of neighboring properties.[1]

A small speck of sphalerite was found by Mr. W. H. Blackburn in the Goldfield-Belmont, but galena has not been noted in any of the mines so far as known. Chalcopyrite, a common mineral in most mining districts, was not found at Goldfield in the course of the present investigation, but it is said to occur sparingly in the Sandstorm and Florence mines.

The common gangue of the unoxidized ore is quartz. This is usually compact, almost flinty, in texture, although porous in mass, and in most cases bears unmistakable evidence of having resulted from the silicification of dacite, rhyolite, or andesite. Large vugs and conspicuously crystalline quartz, such as are found in typical veins the world over, are practically absent from the Goldfield district, where the free development of quartz crystals in open spaces is represented only by drusy films, lining pores left by the solution of phenocrysts or incrusting small interstitial cavities in brecciated material.

Associated with the quartz in much of the ore are soft white substances, such as the miners commonly call "talc." Chemical

[1] Ransome, F. L. "Preliminary Account of Goldfield, etc." Bull. U. S. Geol. Survey No. 303, 1907, p. 36.

and microscopical tests of the white material show that in most cases it is either alunite or kaolinite or a mixture of the two.[1] Sericite, supposed when the preliminary report[2] on the district was written to be also abundant, proves on further study to be very rare and is certainly nowhere an abundant or characteristic mineral in the ore deposits. Gypsum, while not known with actual sulphide ore, is very abundant in the altered rocks within a hundred feet or so from the surface and does occur crystallized with quartz and pyrite on the Goldfield-Belmont mine, below the belt of oxidation.

As a rule, the gold and auriferous sulphides are embedded in quartz. Alunite, however, is often so close to the gold as to appear in the same microscopic field and the telluride of gold in the Jumbo Extension mine is partly embedded in alunite.

The ores, it should be noted, do not occur in typical veins but in masses of shattered, altered rock of very irregular shape. In small part only do they appear to have filled visibly open cavities or fissures.

For descriptions of the oxidized ores, which have been of so much importance at Goldfield, the reader is referred to the advance report cited and to the forthcoming memoir on the district. In some places they contain alum derived from the alunite.

THE ORE-DEPOSITING SOLUTIONS.

The mineralogical character of the Goldfield ores and the alteration of the wall rock show that the solutions or vapors which deposited them carried gold, copper, bismuth, antimony, a little arsenic and tellurium, hydrogen sulphide, and probably sulphurous and sulphuric acids. The solvent action of the solutions upon quartz was comparatively slight, as shown by the fact that the original phenocrysts of the dacite still retain their characteristic embayed outlines when the rest of the rock is altered

[1] Mr. E. A. Collins, in his recent good description of the Combination mine (*Mining and Scientific Press*, vol. 95, 1907, p. 398) refers to the ore as "a mixture of soft kaolinized material and hard dacite." The "kaolinized material" is chiefly alunite.

[2] Bull. U. S. Geol. Survey No. 303, 1907, p. 35.

to quartz, alunite and kaolinite. The quartz set free by the decomposition of the silicates has for the most part recrystallized as fine-grained aggregates. A small proportion, as we have seen, has been carried away in solution, perhaps in part to be recrystallized in small neighboring fissures, and in part permeating the surrounding less altered rocks. Large masses of coarsely crystalline vein quartz are absent from this district and it seems necessary to conclude that the ore-bearing solutions were not only poor in silica but that, in spite of their energetic attack upon the rocks, they were not good solvents for quartz. The apparently intense silicification of the country rock in proximity to fissures appears at first glance to point to a different conclusion. The conversion of a rock containing 60 per cent. of silica to a fine-grained, pyritic, quartz aggregate does not, however, necessarily imply the direct addition of 40 per cent. of silica. The result may be attained by the removal of most of the bases, the conversion of the iron to pyrite and the development of a porous texture such as is favorable for ore deposition and is characteristic of the Goldfield ledges. Moreover, it is probable that some of the silica shown to have been abstracted from the altered dacite may have been concentrated in the immediate vicinity of the fissures. Certainly, whatever silica was originally in the solutions did not travel far from the fissures through which they rose.

Whether the solutions were notably ferruginous is doubtful. As compared with other districts, the pyrite at Goldfield is not abundant and all of that in the country rock can, as has been shown, be accounted for without any addition of iron. There has, in fact, been an abstraction of iron which may have been sufficient to form the pyrite in the actual ore, upon the supposition that the dissolved iron, like the silica, migrated toward the fissures.

In general the heavy metals brought in by the solutions remained within or very close to the multitude of small, irregular fissures that afforded opportunity for the depositional process. The sulphur acids, on the other hand, penetrated the wall-rock for considerable distances.

It is very probable that the ore-bearing solutions contained carbon dioxide, although the ores and the rock adjacent to them are free from carbonates. Field evidence in this district, as well as in the Cœur d'Alene district[1] in Idaho, indicates that this constituent, when of volcanic origin, becomes active in the formation of carbonates only at comparatively low temperature and that it tends to penetrate to greater distances from the source of supply than some of the other constituents. The third, or propylitic type of alteration described on page 671, is thought to be largely due to the extensive permeation of the rocks by solutions containing carbon dioxide. It thus constitutes an outer aureole to the more intense metasomatism associated directly with the ores. I hope at a future time to study in detail the relation of the metamorphism particularly described in this paper to that of this outer zone.

It may be recalled, in this connection, that Sainte-Claire Deville and Leblanc,[2] in their studies of Italian volcanic gases, found that sulphurous and carbonic acids never occurred together, although the association of sulphydric and carbonic acids was frequent. They concluded that, as a rule, the emanation of carbon dioxide marks a later and cooler stage of solfataric activity. The transition from one type to the other, however, can hardly be abrupt.

Just what became of the lime and magnesia removed from the altered dacite has not been determined. A part, at least, of the calcium was probably taken into solution as hydrous sulphate and deposited in fissures as gypsum, this mineral being known to occur in the district in places where its formation can scarcely have resulted from the action of surface waters. Still another part and some of the magnesium may have been carried as carbonates into the rocks affected by metamorphism of the third or propylitic type and there deposited metasomatically as calcite or dolomite. It has not yet been ascertained, however, whether

[1] Ransome and Calkins. "The Geology and Ore Deposits of the Cœur d'Alene District." Profess. Paper U. S. Geol. Survey. In press.

[2] "Mémoire sur la composition chimique des gaz rejetés par les évents volcaniques de l'Italie méridionale." *Ann. de Chimie et de Phys.*, vol. 52, 1858, p. 45.

there has actually been any addition of calcium or magnesium to these carbonatized rocks.

Two general hypotheses are entertainable with reference to the source of these solutions. They either came from above, the sulphurous or sulphuric acid having been derived from overlying deposits of oxidizing sulphides, or they came from below. In the former case the solutions were presumably cold; in the latter case they were in all probability hot. The difficulties in the way of the descensional hypothesis, however, appear to be insurmountable.

All available geological evidence indicates that the ore deposits of Goldfield were formed comparatively near the surface and that consequently they do not represent the final stage of a long period of erosion and progressive downward enrichment. The irregularity and sporadic occurrence of the ore bodies would seem to be alone sufficient to render any such long-continued enrichment impossible. We are driven then to suppose that if descending solutions effected the intense metasomatic action described, these must have derived their chemical energy from the oxidation of moderate quantities of pyrite comparatively near at hand. Under such circumstances, the effect produced appears to be greatly disproportioned to the available agency. Such a process might account for the development of kaolin and perhaps some alunite within the oxidized ore, but hardly for the extensive metasomatism of the country rock which is not limited to the vicinity of known ore bodies and continues far below all traces of oxidation as measured by the presence of iron oxides. For it is to be borne in mind that the alteration described in this paper is characteristically associated with unoxidized ores and that gold, pyrite, tetrahedrite, bismuthinite and the other minerals found in such ores were deposited at the same time that the neighboring rock was changed to quartz, alunite and kaolinite. If the alunitization is the work of cold descending solutions then the rich ores of Goldfield are entirely the product of the same agency. In the light of our present knowledge of ore deposition, this seems improbable.

The intensity of the alteration and the character of the solutions, as shown by the composition of the ores and by the metasomatism of the country rock, point to hot ascending waters as the effective agent. Even the alunite, in spite of the occurrence of the mineral in the oxidized ore of some of the Cripple Creek mines and the view held by De Launay with regard to the Tolfa occurrence, is suggestive of more intense chemical activity than is usually manifested by cold oxidizing solutions. The Goldfield region, moreover, is known to have been the scene of volcanic activity throughout most of Tertiary time. That the solutions were essentially emanations from a solidifying body of dacitic magma—the reservoir whence came the intrusive dacite and the extrusive dacite vitrophyre of the district, is regarded as a probable hypothesis. It is significant in this connection that a chemical analysis of the glassy, effusive dacite vitrophyre shows 3.35 per cent. of water driven off below 110° C. and 4.06 per cent. lost above that temperature, a total of 7.41 per cent. The intrusive dacite on the other hand contains 2.95 per cent. of water, 2 per cent. being driven off above 110° C. The dacitic magma thus originally contained a large quantity of water and that much of this water has been expelled during crystallization is shown by the difference of over 4 per cent. between the water of the two analyses.

The limits of a brief paper do not permit of a full discussion of the question of the thickness of the overlying rocks at the time the ores were deposited. General geological evidence which will be set forth in a later publication indicates that the ores were deposited at comparatively shallow depth.

ORIGIN OF KAOLINITE.

Some discussion has been waged in the literature of ore deposits regarding the origin of kaolin and Mr. Lindgren[1] has recently intimated that, although he himself formerly referred to it as characteristic of certain classes of veins, kaolinite should

[1] "The Relation of Ore-deposition to Physical Conditions." This journal, vol. II., 1907, p. 120.

not be considered as a gangue mineral of any class of ore deposits except those formed under the influence of oxidation. In a subsequent paragraph he somewhat modifies this statement by the expression of belief that "kaolin is rarely formed by alkaline hot water at any considerable depth below the surface."

Much kaolin originally described by various authors as formed by the solutions which first brought up the ores associated with it, has later been proved to have resulted from oxidizing processes, it being one of the most characteristic products of the action of percolating acid solutions upon aluminous rocks. The kaolin at Cripple Creek is a good example. Much so-called kaolin, moreover, has been shown to be sericite, and some is perhaps alunite. These facts, however, seem scarcely to warrant the total elimination of kaolinite from the list of gangue minerals found in unoxidized ore deposits. The mineral undoubtedly occurs as an original constituent of some of the ores of the San Juan Mountains, Colorado.[1] Mr. W. H. Weed[2] has described it as a product of the metasomatic action of the waters of Boulder Hot Springs, Montana, upon granite, and according to Mr. S. F. Emmons[3] the mineral is an abundant original constituent of the ore of the Bassick mine. Kaolinization has also been noted by Béla von Inkey[4] in the dacitic country rock of the Nagyág veins, the material being afterwards investigated by F. Kollbeck,[5] whose analysis indicates a mixture of kaolinite and sericite.

At Goldfield, the intimate association of the kaolinite with the alunite, gold and sulphides shows that all were formed at the same time and by one general process which was anterior to and entirely independent of oxidation or weathering. These latter

[1] Ransome, F. L. "Economic geology of the Silverton Quadrangle, Colo." Bull. U. S. Geol. Survey No. 182, 1901, p. 73.

[2] "Mineral Vein Formation at Boulder Hot Springs, Montana." 21st Ann. Report U. S. Geol. Survey, 1900, part 2, p. 253.

[3] "Geology of Silver Cliff and the Rosita Hills, Colorado." By Whitman Cross. Accompanied by a paper on the mines of Custer County, Colorado. By S. F. Emmons, 17th Ann. Rept. U. S. Geol. Survey, 1896, part 2, p. 432.

[4] "Nagyág und seine Erzlagerstätten." Budapest, 1885, p. 143.

[5] "Untersuchungen über die Zersetzung des Quarztrachyts neben Golderzgängen von Nagyág." *Oesterr. Zeits. f. Berg- und Hüttenwesen*, vol. 36, 1888, pp. 25–27.

processes have probably also resulted in the formation of some kaolin, but with this secondary development the present paper is not concerned beyond the pointing out of the distinction between the two modes of genesis.

CONCLUSION.

The recognition of alunite as a characteristic constituent of the Goldfield ores and the demonstration of its genetic relation to them establishes a new type—that of alunitic and kaolinitic gold-quartz veins, in the classification of epigenetic deposits based upon the kind of metasomatism effected in the wall-rock by the ore-depositing solutions. While the Goldfield deposits are probably too irregular in form to come under the usual definition of vein, yet in all that relates to genesis of the ores there is no essential difference between them and what is usually termed a metasomatic fissure-vein.

It is not believed that the Goldfield district is unique in the possession of this type. Other examples are likely to be found among the great number of ore deposits associated with Tertiary volcanism, particularly when more investigators of mining districts realize the importance of close studies of rock alteration, such as have been so admirably carried out in this country by Mr. Lindgren and in Europe by the late Professor Stelzner, and when they accept neither kaolinite nor sericite on faith and external appearance.

In spite of the mass of evidence which indicates the deposition of a large class of gold veins by highly siliceous alkaline solutions, it is clear that some deposits, and those of remarkable richness, may be formed by acid solutions. To explain this essential difference in the vein solutions is one of the most absorbing problems connected with ore genesis. It is possible that emanations from a crystallizing magma may be normally and initially acid but become modified by passage upward through the rocks. If there is any truth in this suggestion, then ores such as those of Goldfield are deposited comparatively near to the source of the solutions. Of course, the extent to which

initially acid emanations would be neutralized and modified in their ascent through fissured rock would depend not only upon distance but very largely upon the kind of rock traversed, the quantity and character of admixed surface-derived waters, and the pressure and temperature gradients.

It may also be pointed out that the constituents removed from the Goldfield rocks are those which are deposited extensively in the production of gold-quartz veins of the sericitic and calcitic type. Consequently, conditions are easily conceivable under which the acid solutions of Goldfield might have ascended through a much thicker series of rocks and given rise to sericitic and calcitic veins.

Finally, the relation of the alunite and kaolinite at Goldfield suggests the attractive possibility of the future discovery of metasomatic veins of the pure alunitic type, without kaolinite.

While the available facts in the Goldfield district appear to justify the conclusions drawn in this paper, the cautious reader may well share with the writer a certain reserve in judgment, in view of the moderate depth, about 300 feet, to which study of these deposits has necessarily been limited. The possibility that more than one process has contributed to the concentration of the sulphide ores and to the alteration of the rocks is one that cannot be entirely eliminated until the mines have been opened to greater depths.

THE WEATHERING OF COAL.

S. W. Parr and N. D. Hamilton.

In coöperation with the Illinois State Geological Survey and the Engineering Experiment Station, the Chemical Department of the University of Illinois has conducted during the year past a series of tests on the weathering of coals. The storing of coal is coming to be more and more a necessary practice in many industrial operations and the question of deterioration enters as a very vital factor in the case. That such deterioration occurs is conceded by everyone, but exact data as to its extent or information as to the conditions which retard or promote it are meagre. Storage plants with capacities ranging from 50,000 to 150,000 tons are becoming frequent. Each percent of deterioration in a storage heap of the smaller size represents a loss of the equivalent of 500 tons of coal. This is a serious proposition if true and the present series of experiments was devised for the purpose of developing, if possible, some of the facts connected with the matter.

Richter, after extended experiments in 1868, formulated an explanation for the weathering of coal, which does not seem to be disproven by more recent experimenters, to the effect that the weathering of coal is due to the absorption of oxygen, a part of which goes to the oxidation of carbon and hydrogen in the coal, and part is taken into the composition of the coal itself. We certainly need more definite information in order to formulate a final and satisfactory explanation of all the phenomena involved, but Richter's theory conforms to many of the known conditions and indicates the close relationship between the matter of deterioration and spontaneous combustion.

The experiments herein described had the disadvantage of being conducted upon a relatively small scale, in lots of ten to

twenty pounds. It may be questioned whether deterioration in large heaps would be at a corresponding rate. Still, certain conditions seem to attend the process of weathering and a knowl-

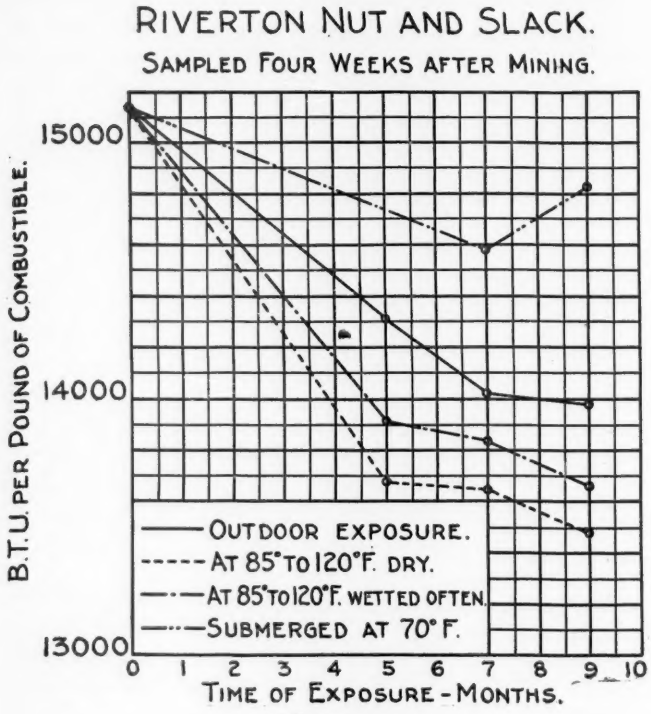
RIVERTON NUT AND SLACK.
SAMPLED FOUR WEEKS AFTER MINING.
B.T.U. PER POUND OF COMBUSTIBLE.
15000
14000
13000
OUTDOOR EXPOSURE.
AT 85° TO 120° F. DRY.
AT 85° TO 120° F. WETTED OFTEN.
SUBMERGED AT 70° F.
0 1 2 3 4 5 6 7 8 9 10
TIME OF EXPOSURE - MONTHS.

FIG. 71.

edge of these facts is a necessary preliminary to the more extensive study of the subject, which we hope to follow out.

The conditions under which the coals were studied were as follows: The starting point, of course, was the coal in its normal state, that is, as nearly as possible, corresponding to the condition existing when broken out of the vein. The time between the mining of the coal and the initial analysis varied somewhat,

but the first series of tests was made as soon as possible after the mining of the coal. In the light of subsequent developments, greater stress should be put upon the early examination of samples to determine the initial condition. Even under the most

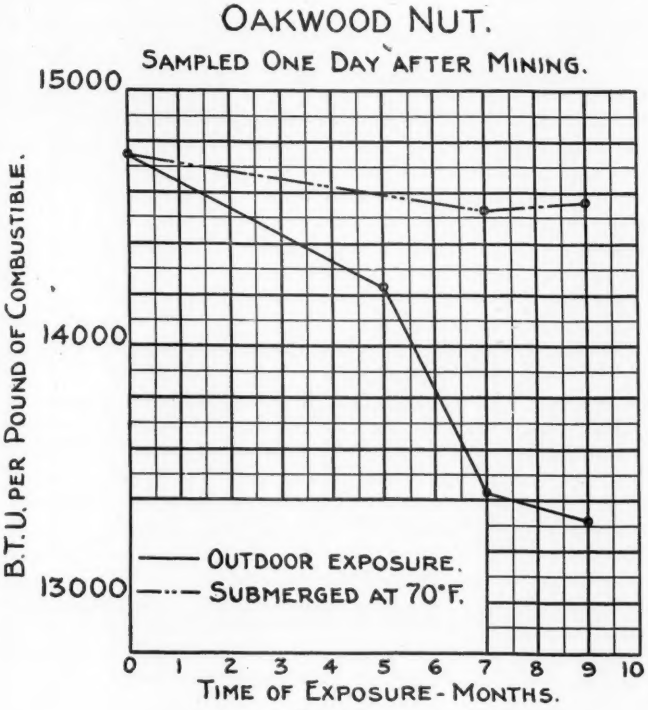

FIG. 72.

careful disposition of samples in laboratory containers, a deterioration takes place which, while not strictly a weathering process, is still a large element in any study of the case and must be considered, if exact conclusions are to be available.

The coal used was of small lump or nut size, each sample, of approximately one hundred pounds, was subdivided in order to

subject the same kind of coal to various conditions. The conditions were to be continued through nine months and were as follows:

(*a*) Outdoor exposure.

(*b*) Exposure to a dry atmosphere at a somewhat elevated temperature, ranging between 85° and 120° Fahr.

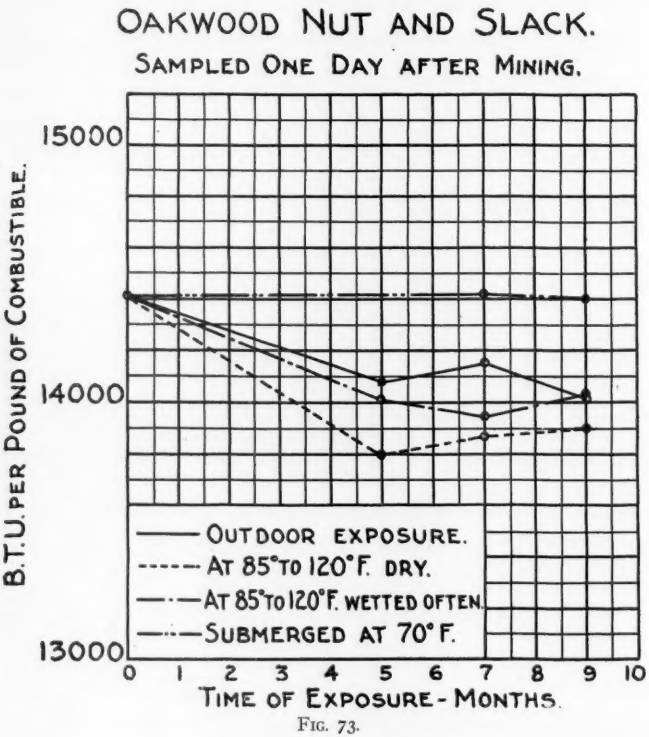
OAKWOOD NUT AND SLACK.
SAMPLED ONE DAY AFTER MINING.
B.T.U. PER POUND OF COMBUSTIBLE.
15000
14000
13000
0 1 2 3 4 5 6 7 8 9 10
TIME OF EXPOSURE - MONTHS.
OUTDOOR EXPOSURE.
AT 85° TO 120° F. DRY.
AT 85° TO 120° F. WETTED OFTEN.
SUBMERGED AT 70° F.

FIG. 73.

(*c*) Under the same conditions as (*b*) so far as temperature was concerned, but to be drenched with water two or three times per week.

(*d*) Submerged in ordinary water at a temperature approximately 70°.

The periods for examination were divided as nearly as the work would permit into

1. The initial analysis of the fresh coal.
2. After exposure for five months.
3. After exposure for seven months.
4. After exposure for nine months.

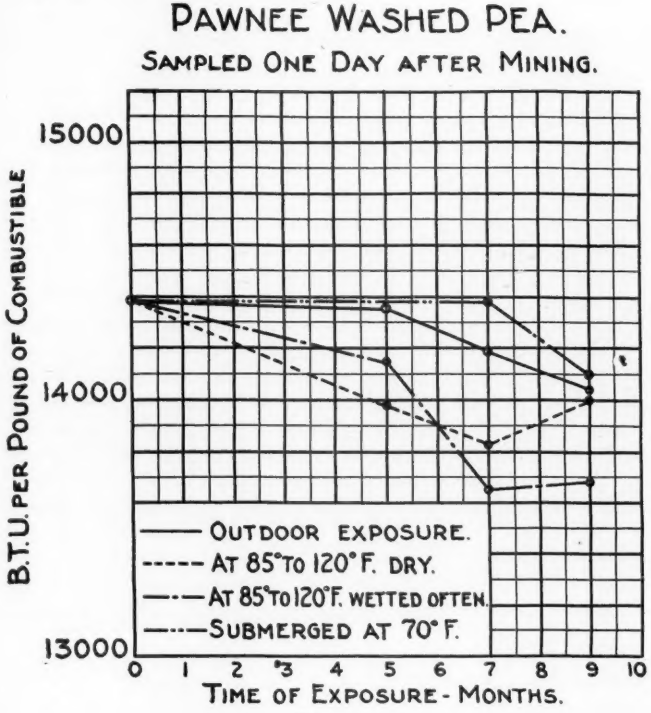
PAWNEE WASHED PEA.
SAMPLED ONE DAY AFTER MINING.
B.T.U. PER POUND OF COMBUSTIBLE
15000
14000
13000
0 1 2 3 4 5 6 7 8 9 10
TIME OF EXPOSURE - MONTHS.
OUTDOOR EXPOSURE.
AT 85° TO 120° F. DRY.
AT 85° TO 120° F. WETTED OFTEN.
SUBMERGED AT 70° F.

FIG. 74.

For the sake of comparison also the calorific values were determined under uniform conditions throughout by means of the Parr calorimeter and the results calculated to the ash- and water-free basis to eliminate any variations in the process of sampling

and to make as far as possible the different samples as well as the different lots comparable among themselves. The results for each sample are charted in the diagrams herewith (Figs. 71

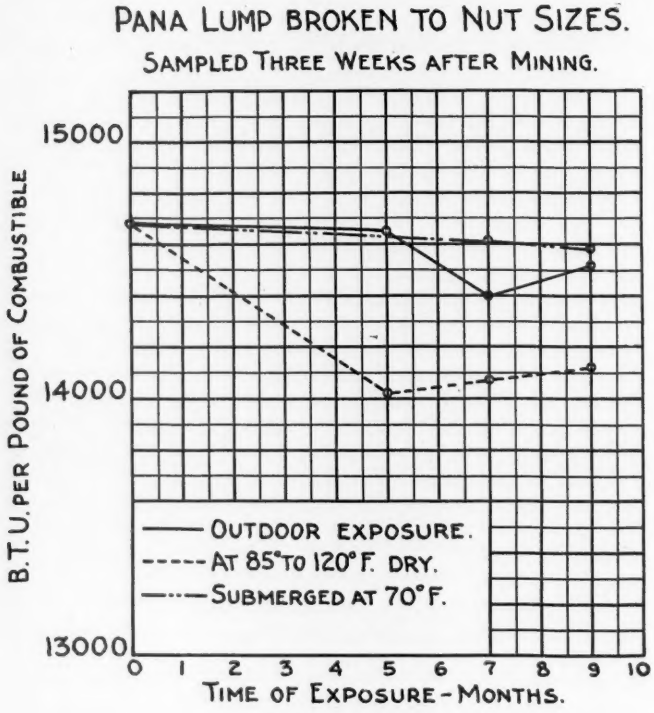
PANA LUMP BROKEN TO NUT SIZES.
SAMPLED THREE WEEKS AFTER MINING.
B.T.U. PER POUND OF COMBUSTIBLE
15000
14000
13000
OUTDOOR EXPOSURE.
AT 85° TO 120° F. DRY.
SUBMERGED AT 70° F.
0 1 2 3 4 5 6 7 8 9 10
TIME OF EXPOSURE - MONTHS.

FIG. 75.

to 79, inclusive). These charts are used by courtesy of the Engineering Experiment Station of the University of Illinois.

The diagrams show a distinct difference between the submerged coal and the samples exposed to the air. If we omit Figs. 71 and 74, it may be fairly said that no deterioration has taken place in the case of the submerged samples. It is not

improbable that the initial value for the coal in Fig. 71 is too high, due to variations in sampling or less familiarity of the operator as to methods, etc. Indeed, as a whole, the values found for the submerged coal throughout the nine months did not vary by greater amounts than would be expected with the inevitable modifications due to sampling, temperature and other variables of manipulation or surroundings.

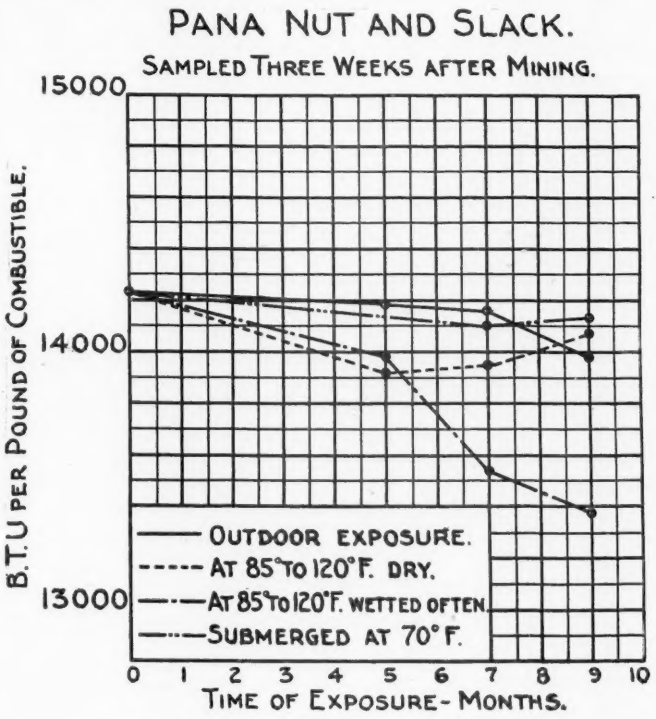
PANA NUT AND SLACK.
SAMPLED THREE WEEKS AFTER MINING.
15000
14000
13000
B.T.U PER POUND OF COMBUSTIBLE.
OUTDOOR EXPOSURE.
AT 85° TO 120° F. DRY.
AT 85° TO 120° F. WETTED OFTEN.
SUBMERGED AT 70° F.
0 1 2 3 4 5 6 7 8 9 10
TIME OF EXPOSURE - MONTHS.

FIG. 76.

If we next consider the charting of the results obtained from samples subjected to outdoor exposure, we find wide variations in amount, but a uniformity as to the fact of marked deteriora-

tion. These samples were placed in shallow boxes on the nearly flat roof of a building and subjected alike to the changes of temperature and moisture common to the months from October to July. The treatment, therefore, was identical. The variations,

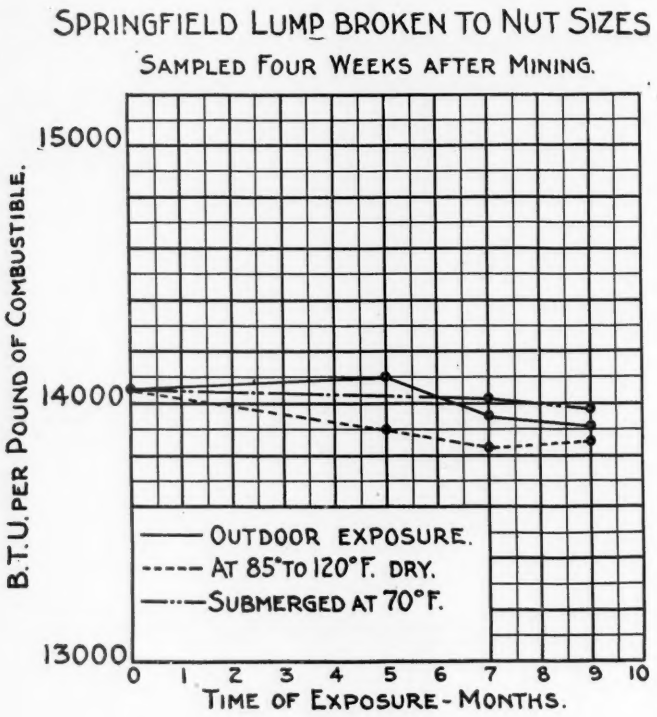
SPRINGFIELD LUMP BROKEN TO NUT SIZES
SAMPLED FOUR WEEKS AFTER MINING.
B.T.U. PER POUND OF COMBUSTIBLE.
15000
14000
13000
OUTDOOR EXPOSURE.
AT 85° TO 120° F. DRY.
SUBMERGED AT 70° F.
0 1 2 3 4 5 6 7 8 9 10
TIME OF EXPOSURE - MONTHS.

FIG. 77.

which range from 2 to 10 per cent. of loss in heat values must be ascribed to inherent properties of the coals themselves. While all showed more or less of the tendency to disintegrate, they varied distinctly in the ease with which they would crumble under pressure.

If we consider next those samples represented by the dotted line or those subjected to a thoroughly dry atmosphere and at a slightly elevated temperature, we will find with but one exception, Fig. 78, a greater deterioration than in the case of outdoor

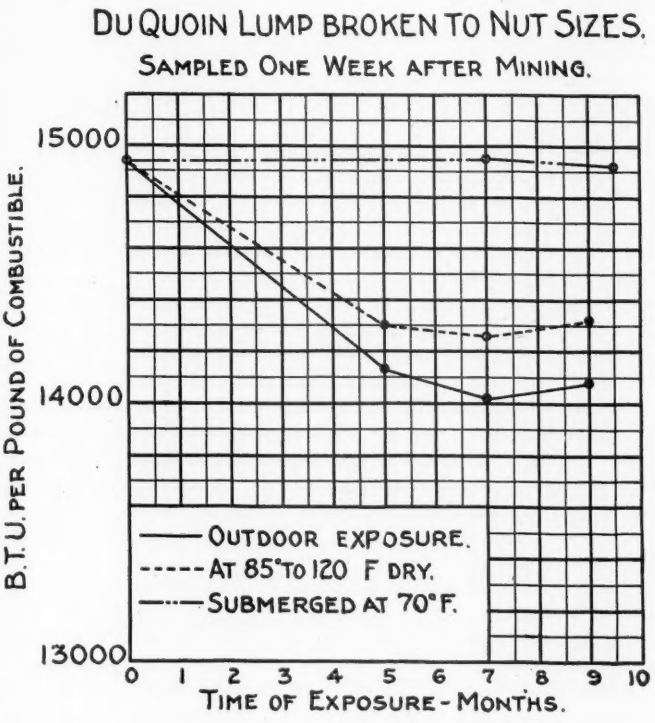
DU QUOIN LUMP BROKEN TO NUT SIZES.
SAMPLED ONE WEEK AFTER MINING.
B.T.U. PER POUND OF COMBUSTIBLE.
15000
14000
13000
0 1 2 3 4 5 6 7 8 9 10
TIME OF EXPOSURE - MONTHS.
OUTDOOR EXPOSURE.
AT 85° TO 120 F DRY.
SUBMERGED AT 70° F.

FIG. 78.

exposure, and even in this exception the losses in both cases may be fairly said to be equal. Here is a rather unexpected result in that ordinarily a roof over coal in storage is supposed to be preferable to open exposure. It is true that coal, in large masses, where heating might more readily occur as a result of wetting

from rains, might behave differently; but, under the conditions, the results are as stated.

Finally, the samples subjected to high temperature with frequent wetting down, conform in general behavior to those samples exposed to outdoor influences. Where differences occur, as in Figs. 76 and 79, the deterioration is greater in the case of samples having the frequent wetting and drying out process.

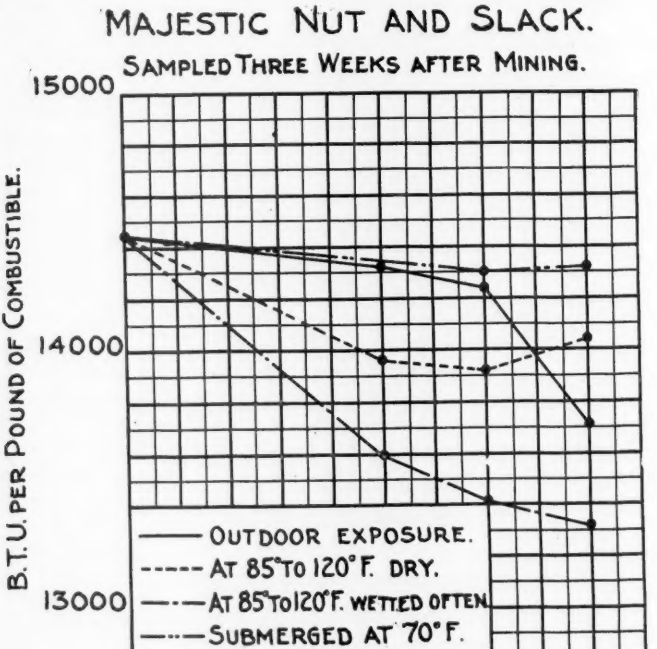
MAJESTIC NUT AND SLACK.
SAMPLED THREE WEEKS AFTER MINING.
15000
14000
13000
B.T.U. PER POUND OF COMBUSTIBLE.
OUTDOOR EXPOSURE.
AT 85° TO 120° F. DRY.
AT 85° TO 120° F. WETTED OFTEN
SUBMERGED AT 70° F.
0 1 2 3 4 5 6 7 8 9 10
TIME OF EXPOSURE - MONTHS.

FIG. 79.

Here, again, the results are undoubtedly variable in accordance with the variation of structure and composition of the coals themselves. In general, we would expect greater persistency of

values in the dense and less friable coals and in those with less of iron pyrites throughout their texture.

After beginning these experiments certain investigations in other lines gave evidence of an initial loss of values due to the escape of volatile hydrocarbons in the time immediately following the breaking out of the coal from the seam. To what extent or with what speed such loss occurs has not been determined as yet, but it is a fact to be considered in any experiments intended to show relative losses by weathering. In the experiments here outlined this factor was not taken into account, except that all samples were obtained as quickly from the mine as would be the case in the commercial handling of the coal from mine to market.

SUMMARY.

(*a*) Submerged coal does not lose appreciably in heat value.

(*b*) Outdoor exposure results in a loss of heating value varying from 2 to 10 per cent.

(*c*) Dry storage has no advantage over storage in the open except with high sulphur coals, where the disintegrating effect of sulphur in the process of oxidation facilitates the escape of hydrocarbons or the oxidation of the same.

(*d*) In most cases the losses in storage appear to be practically complete at the end of five months. From the seventh to the ninth month the loss is inappreciable.

(*e*) The results obtained in small samples are to be considered as an index of the changes affecting large masses in kind rather than in degree, but, since the losses here shown are not beyond what seems to conform in a general way to the experience of users of coal from large storage heaps, it may be not without value as an indication of weathering effects in actual practice.

Further studies are to be continued, having reference to actual storage conditions.

DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

THE FAULT PROBLEM. II.

THE PREVALENCE OF EXTENSIONAL FAULTING.

In the growth of the earth, according to the planetesimal hypothesis, the self-compression of the earth-mass was a source of heat. Computation indicates that the distribution of this heat should be such that over something like three-fourths of the radial distance from the center, the temperature is falling owing to the outward flow of the heat, while in the remaining portion, except so much of the outer part as is sensibly affected by surface loss, the temperature is rising.[1] In this outer part the temperature is essentially stationary. It follows from this distribution that the loss of heat in the central portion tends to shrinkage in that portion, while the rise of heat in the middle zone tends to expansion in that portion. There is obviously a neutral horizon between these portions, and, as remarked, there is on the exterior a shell whose temperature is nearly constant. Whensoever the tendency to shrinkage in the central part overmatches the resistance to deformation arising from the rigidity of the earth's body, shrinkage should follow, carrying down all

[1] Whatever heat is generated in the middle zone by radio-activity cooperates with this. The limits of this article, however, do not permit a discussion of this factor. The peculiar mode of distribution of the heat due to self-compression is shown diagrammatically in Chamberlin and Salisbury's "Geology," Vol. I., p. 566.

the outer portion. The mode of deformation, however, should not be the same for the shell as for the middle zone. The shell from its unchanging temperature should suffer folding and thrust-faulting in accordance with familiar doctrine, while the middle zone should be deformed by distributive shear of the quasi-flowage type, because of the load under which the deformation must take place. The heat which is added to this middle zone is simply that transferred from the interior, and hence the loss of the interior in volume may be assumed to be equal to the gain of the middle zone, or at least approximately so. But the portion of the earth which resists the shrinkage of the central part is much larger than the portion which resists the expansion of the middle zone; hence it seems a sure inference that the two portions will reach their critical points of action at different times, and therefore there will be two sets of deforming periods, which work coöperatively, in a sense, but yet, in a sense, independently. The periods due to the shrinkage of the interior are probably several times as long as the periods due to the gain of heat in the middle zone. There may therefore be several stages of deformation of the latter class between any two periods of the former class.[1]

1. On its face it would appear that, if the middle zone is gaining in temperature and hence expanding, while the shell at the surface remains stationary in temperature, tension should be developed in the latter, and that we might find in this tension a promising basis for explaining the prevalence of tensional faulting; but on consideration its value is seen to be very doubtful. In the first place, the transfer of heat is a very slow process, and its quantitative effects, simply as an expansional agency, come out small when submitted to computation. So true is this that I do not look to change in temperature as being, *in itself*, a very potent factor in any of the deformations of the earth, except those immediately connected with vulcanism. The greater de-

[1] This twofold periodicity affords a promising suggestion as to a natural division of geologic time into technical eras and periods. This will be the subject of discussion in another publication.

formations probably arise from molecular readjustments and sub-molecular changes. Changes of temperature, besides affecting the volume directly, are among the most effective means by which molecular rearrangements and perhaps sub-molecular changes are effected, and therefore they are more or less talismanic of changes associated with themselves and perhaps more effective.

A more special reason for supposing that the effect of rising temperature in the middle zone is of little influence in swelling its volume, lies in the belief that the added heat is largely consumed in the solution or fusion of such constituents of the middle zone as are susceptible to such action with a very slight increase of heat above that which they already possess. My conception is that with every slight increase of heat some constituents which could not previously enter into solution or fusion under the existing pressures are permitted to do so by such addition, and that the portions which thus become mobile are acted upon by the differential stresses within the earth, especially the tidal stresses, and are forced toward the surface and at length emerge volcanically.[1] It will be seen that this process should always leave the middle zone in a state of critical relationship between the existing temperatures and pressures, and the solution or fusion points *of the next most soluble or fusible constituents—not of the whole mass*—and hence that each successive rise of temperature should mobilize some small fraction of the mass and thus continually feed the volcanic process. The rising heat of the middle zone is thus believed to result, by transformation into solution-fusion heat, chiefly in the extrusion of lavas, and hence to do but little expansional work.

Now the transfer of lavas from below the crust to its surface, tends toward crustal depression and hence crustal thrust.

On the whole, therefore, it is probable that these indirect effects of rising temperature in the middle zone which tend toward thrust are greater than the direct ones which tend toward expansion and shell tension. We cannot then probably look to

[1] "Geology" cited, Vol. I., pp. 578–579, 629–632; Vol. II., pp. 103–104.

this as an effective source of normal faulting. Large extrusion of lava from a given vent or fissure must doubtless result in local depressions of the shell, and this may produce circumscribed faulting of its appropriate kind, within the area so affected. Lavas intruded within or beneath the shell and producing bulges of the surface, doubtless also produce appropriate tensional faulting of circumscribed extent, but these can hardly be held to help much in meeting the requirements of the main problem of the prevalence of normal faulting.

2. When the great deformations of the earth are in progress, it is conceived that thick segments, which have become somewhat differentiated in constitution, crowd upon one another, and that certain portions are made to bulge and to constitute the great protuberances of the earth-spheroid. In so far as any portion of the shell takes on an increased curvature by reason of protrusion actuated from below, the normal result is a stretching of the outer part of the shell, and this may give rise to tensional faulting. This was doubtless applicable to the continents in their original formation, but the continents had their initial protrusion so long ago, and under such conditions, that they cannot be cited here to advantage, but further protrusions of the continents seem to have occurred at intervals within the stratigraphic period, and bulgings of the earth into plateaus and mountain swells were notable features of the later geologic times, and have probably been periodic events throughout the earth's history. It might seem, therefore, that there is in these protrusive actions an appropriate agency of normal faulting. This has been widely recognized, and, to a notable extent, it is doubtless a true cause. But it is apparent that such faulting must be confined to the protuberances themselves and must be properly proportioned to the degree of protrusion. In testing the value and applicability of such vertical protrusion, two factors are to be considered, —its competency to produce vertical offset and its competency to produce lateral extension.

Its competency to produce vertical offset may be a large fraction of the total vertical movement, for one block may move little

or none, while another may suffer nearly or quite the maximum of motion. If the fault planes are nearly vertical, or have nearly parallel slopes, no lateral extension is necessarily involved even in considerable vertical offset.

But if we test by computation the probable value of bulging as a source of lateral extension, the result is found to be small. If, for example, an arc 1,200 miles long be bowed symmetrically upwards by vertical action to the extent of three miles in its central portion, it would be stretched only 1/1,860 of its length, or less than 3 feet per mile, 3,400 feet in all. Applied to the west American plateau at its widest point, an arc of 1,200 miles length would reach from the California coast in 40° lat. to about the mid-slope of the great plains near the western limit of Kansas, in other words would not quite span the full breadth of the actual swell. The assigned elevation of three miles is probably much more than the plateau ever suffered, if one may judge by the various physiographic indices. Geologists familiar with the plateau region will realize the utter inadequacy of 3,400 feet to meet the surface extension implied by the observed faulting, unless it has been seriously misinterpreted. If the arc were only 150 miles long and the bulge still three miles, the surface extension would exceed that of any known case of this class, and yet it would average only about 9 feet to the mile, or 1,350 feet in all.[1] It appears therefore that simple arcuate protrusion is competent to give but a small fraction of the lateral extension which observed data seem to require.

3. If the protuberances formed by bulging sink backward under gravity by means of a deep-seated flowage attributed to a viscous or plastic subcrustal zone, the effect upon the surface extension will be the reverse of the bulging process, and a crowding and lateral thrust, comparable to the tension experienced in bulging, will follow normally. In so far therefore as we postulate subcrustal viscousness or plasticity and bring it into action in the form of deep-seated flowage, we introduce an agency

[1] The precise form of the arching, of course, modifies the result, but the variation is of negligible importance in this application.

inimical to normal faulting, so far as applicable to this case.

If, however, on the contrary, we assign to the deeper horizons an effective rigidity sufficient to maintain the great protuberances in their protuberant form, a feature is introduced which we need now to consider.

4. In the production of thrust faults, as usually interpreted, the gravitative force is divided into two components, one of which pulls the crust downwards, the other of which forces it horizontally, the latter being the thrust expressed in folding and its associated faulting. In a protuberance maintained as such by the rigidity of its base, the gravity of the shell is likewise divisible into two components, one of which pulls downward and is resisted by the rigidity of the base, the other of which pulls laterally. This second component, though much weaker than in the previous case, is yet a continuous tensional agency acting upon the shell of the protuberance.

The effect of gravity on a continental protuberance may be studied advantageously from its analogy to the effect of gravity on a glacier, for continents and continental glaciers are close analogues dynamically, since both are masses of crystalline rock and both are affected by an internal transfer of their constituent molecules from one attachment to another. If any geologist is disposed to file a demurrer here as to the competency of the molecular changes in ordinary crystalline rocks to give movements comparable to those of glaciers, it is to be noted that the competency is not presumed to be at all equal in efficiency but merely similar in kind. A relative efficiency of 1/10,000, or perhaps even 1/50,000, on the part of rock, would apparently meet the demands of the case, when the relative gravities are considered. The continental protuberances, measured from the ocean floor, have thicknesses ranging from two and a half to six miles, neglecting mountain peaks, and are subject at their bases to pressures of 15,000 to 35,000 pounds per square inch, roundly speaking, and to proportionally less pressures at higher levels. These pressures develop stresses in all directions and are opposed by the stresses arising in other portions of the mass and

by the resistance of rigidity. As the stresses in different portions of the mass are all dependent on its configuration and density, it is obvious that stress-differences will prevail throughout all but the central portions of the protuberance, and that, in general, they will be conditioned by the slope of the general surface. These stress-differences will tend to give movement from the more highly stressed portions, under the higher parts, toward the less stressed points, under the lower parts, with modifications due to varying densities and varying resistances of the parts compressed. The stress-differences which will be most likely to produce appreciable results will be those beneath the borders of plateaus and near the edges of the continents. Outward movement in the abysmal borders of the continents will be resisted by the pressure of the ocean, which, at the base of the continental slopes, may be put roundly at 5000 pounds per square inch. This leaves unbalanced pressures in the basal parts of the continental borders of 10,000 to 30,000 pounds per square inch. These are of about the order of magnitude of the surface crushing strength of the rocks of the shell and are not much, if at all, short of the stress-differences necessary to produce granulation and quasi-flowage. The rigidity of rock is probably somewhat increased in the deeper parts by pressure,[1] and for the purposes of this discussion, I shall assume that the effective rigidities of the rocks are, in general, greater than the stress-differences which are brought to bear upon them, though there are exceptions in the case of rocks of specially plastic nature, as also in the case of small portions of rock of other kinds which may be subject to special concentrations of pressure; and of course, the portions which are liquified by solution and by heat belong to the mobile class. In other words, I hold to the essential rigidity of the mass, as such, and make no appeal to viscousness as a *general* property. My appeal is chiefly to the mobility of minute portions acting *in succession,* and especially to the individual transfer of molecules from one attachment to another, while, at any instant, the larger portion of the rock remains in rigid

[1] See Hallock, *Am. Jour. Sci.,* Vol. 34, 1887, pp. 277–281.

attachment.[1] If the mass, as a whole, were viscous in any proper sense of the term, as I understand it, motion under such differential stresses as exist would be a logical necessity at some rate, slower or faster, dependent on the degree of viscous friction.[2] But as the outer part of the earth here under consideration is made up largely of crystalline and other material possessing a notable degree of true rigidity, I do not feel at liberty to make the assumption of viscousness for the general mass, true as it would be for special portions. Such portions as are permanently plastic or viscous are supposed to play some appreciable part in the movement as will be specified later, but not a fundamental part.

Now the rather intense stress-differences that affect the continents are ever-present agencies influencing every change which takes place within these masses in favor of movement in the line of least resistance. A glacier-like creep is therefore postulated, and is assigned chiefly to internal molecular changes acting in ways closely analogous to those assigned to glaciers.[3] Metasomatic and metamorphic changes are in progress throughout all the depths involved in this hypothesis. As in a glacier, water and its vapor are present and aid in molecular transfer both by solution and redeposition, and by alternately entering into and coming out of combination. The same is true of oxygen, carbon dioxide, the sulphur-oxides and other mobile elements and com-

[1] Compare Van Hise, Mon. U. S. Geol. Surv., XLVII., 1904, p. 759.

[2] In a strictly viscous body, as I understand the use of the much perverted term viscous, there is no specific force tending to prevent motion except inertia and friction. The friction may be very high, but friction is only called into play *as motion is set up*, and merely limits its rate. In a rigid body there is a specific force which opposes motion and only permits it in the limited form of strain until this force is overcome. A force must therefore rise to a certain magnitude before it can give rise to continuous movement, in the sense here meant, in a rigid body. A change of form that gives an external impression of "flow" may take place in a solid either by molecular change or by mechanical means, but in both cases it will be different, in real nature, from the flow of fluids or viscous bodies.

[3] "A Contribution to the Theory of Glacial Motion," Decennial Publications, Univ. of Chicago, 1904 (Chamberlin); and "Geology," Vol. I., pp. 308–323, 1904 (Chamberlin and Salisbury).

pounds. Actions of a more mechanical kind, such as crystallization within fissures, the hydrostatic pressure of subterranean waters, changes of temperature, etc., are also in progress and lend their coöperation.[1]

Probably it will not be questioned that this hypothesis of glacier-like creep, considered simply as a hypothesis, has the merit of providing an assignable agency for faulting of the general class called normal, and that it has sufficient breadth of application to meet the requirements of the case. If true, all continental masses and all great plateaus should be affected rather generally by the crevassing assigned to the glacier-like creep, while, at the same time, they should be differentially affected according as they are conditioned by varying heights, slopes, and other sources of stress-differences. The hypothesis also offers an explanation of fissuring, and of the gaping of fissures without faulting. I do not know of any other hypothesis which, in an equal degree, meets the phenomena of normal faulting in that particular which gave to the name *normal*, its superior prevalence. But still it is no more than a hypothesis; it is not even yet a hypothesis that has gone through its preliminiary stages of trial. If this be the true state of the case, we seem rather to be at the beginning of the hunt for the cause of the prevalence of normal faulting, than at the end that calls for nomenclature. The testing of this hypothesis, and the development of others, seem to be the steps next at hand.

The hypothesis of continental creep is susceptible of being tested along three lines: (*a*) By the direct measurement of the assigned movement, just as the movement of glaciers had to be demonstrated before it was universally accepted: (*b*) by the working qualities of the hypothesis when applied to the phenomena of normal faulting and of seismic movement; and (*c*) by the validity of its logical relations in the system of dynamics of which it is a part.

[1] These changes, and this doctrine of mobility by molecular transfer, are set forth at length in Van Hise's monumental work on Metamorphism (Mon. XLVII., U. S. Geol. Surv., 1904). Their applicability is believed to be enhanced by a shear zone supposed to form the base plane of the faulted shell.

(*a*) For direct measurement, adjacent fixed points of reference, such as are so convenient in demonstrating glacial movement, are wanting, but the differential movements of the surface postulated afford a means of test by means of trigonometric surveys. When transcontinental geodetic work shall have been sufficiently extended, and remeasurements shall have been made after a sufficient interval, the spreading of the continents and the movements of their parts will be directly determinable, if such movements are actually taking place. Probably geodetic redeterminations of less extent, when favorably situated, may suffice. There is, indeed, some little evidence of this kind, and some is expected from the surveys in connection with the California earthquake. Latitude and longitude determinations, when specially precise, may also contribute data.

(*b*) A comparison between the special requirements of this hypothesis and the phenomena which it must match, can be made on so many significant points that it gives hope of evaluating the hypothesis while we are awaiting a positive geodetic determination, or at least of showing that the hypothesis is worth testing by geodetic measurements.

1. The hypothesis postulates a *general* tensional state of the shell on the continental and other great slopes. To this there are local exceptions, to be presently noted. At the junction of the continental portion of the shell with the suboceanic portion, the general stress-condition is reversed and thrust prevails. This also will be considered later. The general tensional state of the continental face is in harmony with the common interpretations of normal faults and with the accepted view that they are entitled to be called normal because they are the most common kind. The test on this point lies in the verification or the overthrow of this prevalent view, and this invites a critical resurvey of the whole subject, if there is any ground for doubt about the superior frequency of the normal type of faults.

The hypothesis of continental creep goes farther and offers an explanation of the prevalence of crevices and fissures, and of the fact that these habitually open, and very often remain open

long enough to be filled by deposits from solution, and thus become converted into veins. Herein we touch an economic phase of the subject which will be taken up later. A prevalent state of compression is clearly unfavorable to the gaping of fissures and to the slow reception of vein deposits. It also antagonizes the free circulation of underground waters, a prerequisite to such deposition. Quarrying and mining bear direct testimony as to whether the outer part of the earth is in a state of horizontal compression or not.

2. While a glacier is in a general state of tension, due to the pull of the horizontal component of gravity, it is affected by local compressions where changes of slope occur, and where other agencies cause a local retardation of motion, or an exceptional resistance to motion. The same thing should be true of a creeping continenal rock-mass, for like reasons. Compressional actions should therefore intervene between tensional ones and should manifest themselves by the crushing of weak structures, of fault fillings, of block-edges and so forth, and also, in favorable situations, in compressional or "reversed" faulting.[1] This local intervention of compression is not only a basis for positive testing but is an admonition against the hasty inference of general compressional action from what may be merely incidental to a general tensional action.

3. The depth of the shell which shears over the body of the lithosphere is supposed to be the resultant of the united effects of load, rigidity and shear-resistance.[2] As these factors vary somewhat independently of one another, the depth of the shell should vary, and the shear zone below it should be undulatory. The shear tends to reduce this toward a smooth plane and hence it is probably but gently and broadly undulatory. But if undulatory at all, it would tend to introduce alternate tensions and compressions in the upper surface of the shell as the unequal

[1] Of course I am here using the terms tensional and compressional in their accepted senses in which they refer to the horizontal dimensions. The opposite expression in the complementary vertical dimension is taken for granted, as is usually done.

[2] "Geology" cited, Vol. II., pp. 126–127.

thicknesses of the shell are forced over the inequalities of the sub-shell. The opening and closing of fissures, with consequent facilities for vein-filling, on the one hand, and for crushing, on the other, are presumed to follow, as in the preceding case, of which it is only a special form.

Both of these would give rise to local elevations and depressions of the surface relative to adjacent parts, and to sea-level, and some of the rise and fall on sea-coasts commonly assigned to continental or other large movements, may be merely incidents of the creeping of the shell over the sub-shell. If the evidences of relative rise and fall are variable in distribution and changeable in succession, and are associated with faulted and flexed portions of the shell, the presumption of such an origin is relatively strong.

4. Under our hypothesis, the basal shear-zone is the horizon of greatest faulting, if this shear is to be put in the class of faults at all. Such a movement as that of the shell over the sub-shell implies the displacement of all vertical structures that cross the shear-zone, and if this be a displacement by fracture, it is of the nature of faulting. It is not presumed that the shear zone is usually a single plane but rather a zone of distributive shear. While it is supposed to reach up into the zone of fracture to within three miles or less of the surface, and to be actually forced out to the surface in rare cases, as in the great overthrusts of Scotland, Montana-Alberta, etc., it is also supposed to be distributed downward into the zone of quasi-flowage deformation, and to be expressed in the formation of foliated structures. These latter are not usually regarded as fault-structures, and hence the question as to the advisability of calling this shear structure, a part of which takes place by visible breakage and a part by sub-visible movement of the parts over one another, a fault structure. Here is one of those gradations which are inveterately hostile to all hard-and-fast classifications and nomenclatures.

In respect to the quasi-flowage horizons, it should be understood that I regard the movement of one part over another there

as resisted by greater rigidity and friction than in the horizons of granulation above. I do not entertain the notion of viscousness as properly applicable there at all, as a general property, nor do I entertain the idea of plasticity, in the sense of *easier* mobility, but merely as a conception of the necessary physical mode of deformation when the pressure from load exceeds the breaking strength of the rock. Whatever deformation is forced under these conditions must be without visible fracture and must generally be distributive, and hence must take an expression similar to that of true flowagê. For this I find no better expression than that of quasi-flowage.

5. Actual fluidity, and all of its viscous gradations, are presumed to play a part in the complex phenomena of continental creep, but this I regard as incidental and not fundamental. The shear of the shell upon the sub-shell is supposed to be accompanied by extensive drag, the drag-foliations curving down deeply into the subshell, on the one side of the main shear zone, and far up into the shell, on the other side.[1] Lavas rising from the interior are presumed to take advantage of the lines of least resistance developed by these drag-foliations, as well as of the foliations of the main shear, and to insinuate themselves between the shear-plates, giving a sandwich structure, such as is rather common in the foliated Archean schists, as pointed out by Van Hise, who is of course not responsible for the interpretation here put upon the phenomenon. Now, so long as these lavas are present as insinuated fluids, whether as an incident of their passage across the zone to the surface, or of their lodgment in it, they must act as lubricants and facilitate the motion of the sheets over one another. If the extrusion of lavas were rather active in a given region, this contributary agency might have some notable value. The test of this suggestion is obviously to be found in a correspondence or lack of correspondence between the location of present volcanic action and that of crustal movements of the fault type, as expressed in earthquakes. Such a correspondence is recognizable, but it may perhaps be referred

[1] "Geology" cited, Vol. II., pp. 128–131.

with some plausibility to other modes of action and is not therefore quite conclusive in itself.

6. In a region recently elevated, the stress-difference acts upon a portion of the crust which was not previously stressed in this way, or at least not to the same extent, and there is some ground for the presumption that the rock-material is in a state more susceptible to molecular change than in similar cases of longer standing. Some greater activity on this account is suggested. The validity of this, however, is rather uncertain.

7. One of the best tests of the working value of the hypothesis may be based on the distribution of normal faulting and allied phenomena. In general, the creep should be greatest on the borders of the continents and of the plateaus; it should also be qualifiedly proportionate to the elevation above the ocean floor; in other words, creep is a function of elevation and slope jointly modified by internal structure and composition. The chief slopes of the lithosphere are the abysmal declivities of the continental borders. So far as I know the facts relative to fault-distribution, they are in consonance with the requirements of the theory, but I am not aware that any careful listing and mapping of the normal faults by themselves, so classified as to be suited to a critical test of this kind, has been made.

The distribution of present seismic action is also a most valuable basis for such a test. Earthquakes are clearly more frequent on the borders of the continents than in the interiors, but how closely they could be shown to match the requirements of the theory, it is premature to say, because the details of these requirements need further study. One would probably go a good deal astray, if he were to attempt to predict in detail the glacial motion on the coast of Antarctica or on the unstudied portion of the coast of Greenland.

8. Perhaps the most critical test of the hypothesis, pending positive demonstration by measurement, is found in the nature and behavior of the submarine edges of the continents. These edges constitute the greatest and most definite of all the terrestrial terraces. They are too persistent and distinctive to be

other than the result of some pervasive and effective combination of agencies. The obvious suggestion that they are built out by sedimentation on what were primitively more gradual slopes marking the mergence of the continental swell into the adjacent sub-oceanic basins, undoubtedly compasses an important part of the truth, but if the continental edges were thus built out systematically and were not subjected to unusual modes of deformation and concealment, we might confidently expect to find in the border terranes our most complete series of sediments; certainly so, if we hold that the continents have had any notable degree of permanence. As a matter of fact, the coastal terranes, almost the world over, are conspicuously incomplete, as seen at the surface.[1] There seem to be special reasons of a rather cogent kind for thinking that exceptional action has been in progress on the continental borders. Profound vertical faulting has been suggested, and is, I believe, the favorite view of those who do not subscribe to the doctrine of the essential permanence of the continents. An underthrust of the suboceanic portion of the crust has also been suggested. The hypothesis under consideration makes the continental edge the border of the outward-creep of the protuberant part of the shell. It is there that it joins the sub-oceanic portion which is not subject, or at least not equally subject, to such creep. Resistance to the continental creep is presumably experienced at the border line. The two portions of the shell however meet at an appreciable angle, and overthrusts or folds are assignable as natural consequences of the antagonism. A fault plane of low angle, continuous with the shear plane at the base of the shell, and coming to the surface at or near the base of the abysmal slope, is a conception that does not seem unnatural in itself and appears suited to explain some of the peculiar phenomena already alluded to. So special a view need not however be insisted upon. Fractures, slips, and other stress-products should, under the hypothesis of continental creep, be more prevalent and active near the junc-

[1] The special imperfection of the coastal terranes is discussed in the "Geology" cited, Vol. III., pp. 523–528.

tion of the continental and sub-oceanic shells, than at other places. Earthquakes should spring from this tract more frequently than from others. Seismic data seem to be quite notably in harmony with this. Milne and other special students of seismic distribution have long urged that earthquakes are especially connected with the great abysmal slopes. Hobbs makes the specific statement that "the distant study of earthquakes has shown that they are fifteen to twenty-fold as numerous as formerly supposed, and that over ninety per cent. occur on the floor of the seas, and appear to proceed from the scarps bordering the great ocean deeps."[1] As the accumulation of sediment on the borders of the abysmal slopes is very slow and slight, except perhaps off the mouths of the great rivers, it is not apparent whence the actuating agency of seismic disturbance comes unless it be from crustal movement. Some of the seismic effects seem to be of the kind that originate in rock-movement rather than the superficial slide of loose material. Besides the seismic records, the breakage of submarine cables is furnishing an accumulating mass of evidence of like import.

The notable elongated "deeps" that lie near the foot of the continental slope in some places, notably along the west coast of South America, and the Japan-Kurile border of Asia, perhaps are related to special stresses which arise from the junction of the continental and the sub-oceanic shells and their antagonisms.

9. Coming closer home to the faulting itself, it is apparent that the mode of action assignable to gravity acting in glacier-fashion, is sufficiently distinctive to give some clue to its detection. We might expect both a transverse and a longitudinal system of fissuring and faulting, as in glaciers, attended by many intermediate and divergent forms. Differential rates of movement should give rise to parallel as well as to transverse dislocations, but it would be infelicitous to call the longitudinal dislocations "trans-current," since they are aligned with the

[1] *Science*, XXV., 646, May 17, 1907, p. 766. Also, "Origin of the Ocean Basins in the Light of the new Seismology," *Bul. Geol. Soc. Am.*, Vol. 18, pp. 233–250, 1907.

main current. Inequalities in the base plane should tend to give vertical faulting in lines parallel to the contour of the inequality. The forward movement, attended by a stretching of the surface, should give facilities for the slipping down of wedge-like blocks, and especially for the tilting of blocks. If the shell be taken at 3 to 5 miles thick, as tentatively deduced from the mountain folds, and if the greater of the fracture lines penetrate to its base and join the great basal plane of faulting, such extraordinary and prevalent tilting as that of the Great Basin becomes less inexplicable than under a static view with little or no basal movement. It is obvious that this view introduces complications into the modes of movement and renders their special interpretations difficult, but if it is the true view, it will render them more comprehensible when once their intricate dynamics are mastered, as it has done in the case of glaciers.

10. It is impracticable to go into details here, but the borders of some of the continents, and of some of the great plateaus, take on special expressions which are too suggestive to be passed without a brief mention. I refer to the broadly lobate or arcuate flaps of the shell, usually bordered by mountains, which are especially prevalent on the Pacific border, particularly on the Asiatic side where they have been special subjects of comment by Richthofen, Suess and others. It is not presumed that these were primarily due to creep, but merely that, having been brought into existence by the more powerful thrust-forces of a preceding stage, and having come, by inheritance, into possession of stress-differences arising from the gravity-differences inherent in such reliefs, they presumably give rise to special phases of creep and special distributions of seismic action. There should arise from these peculiar arcuate features of the surface, two dominant stresses lying in the plane of the earth's shell, both of which should tend to tensional fracture and faulting, with accompanying seismic phenomena, the one in lines crossing the arcuate reliefs in a somewhat radial fashion, and the other lying parallel to the arcuate borders. The faulting of the first, so far as due to the pull of the horizontal component of gravity, will run

parallel to the curving horizontal contours of the arcuate relief, and the other transverse to them, and these should be the dominant directions of earthquake faults, so far as referable to this cause. But in the nature of the case there will be many divergencies from these, due to adventitious factors. The greater number of such earthquakes will obviously be on the outer and greater slope of the arc, next the ocean depths. This is in accord with the generalizations of Omori relative to Japanese earthquake faults.

11. There is a distinction of critical importance in the interpretation of such faults on the borders of the continents as seem to be due to thrust. Thrust faults, when the active thrust is *down-slope,* in the large sense, may be due to glacier-like action, just as glaciers thrust mechanically in the direction of their motion or growth when resistance is offered, but active thrusts *from the ocean,* cannot be assigned to this cause. To discriminate the active from the passive factor in a thrust movement has its difficulties, but they are not insuperable and critical studies on this point are much to be desired.

(*c*) The consistency of the postulates of this hypothesis of the origin of the main type of normal faulting with the system of dynamics of which it is made a part, cannot be discussed satisfactorily here without unduly extending this article. Suffice it to say that in making an appeal to molecular changes in a body which remains rigid, as a whole, and in avoiding any appeal to a general "viscous" or "plastic" condition of the interior, considered as a mass, the hypothesis is consistent with the whole system of dynamics which I have tried to build up on the planetesimal hypothesis of the earth's origin. A lithosphere of high and pervasive rigidity seems to be necessary to provide the means for the stress-accumulations which the great periodicities of diastrophism appear to require. Without the postulate of pervasive rigidity, conditioned by modifications due to molecular change, and to local solution-fusion, I am unable to find agencies competent to satisfy the demands of the megadynamics of the earth.

ECONOMIC CONSIDERATIONS.

The general conception of the relations of thrust to tension in the outer part of the earth's shell, which constitutes the soul of the views herein submitted for trial, is not without important bearings on ore deposition. Far from making the two systems of faulting mutually exclusive, and the presence of the one an argument for the absence of the other, the one is made to presume the other, in the following sense; the great bulgings of the outer part of the earth, which are assigned to compressive deformation and are accompanied by compressive faulting, are made the conditions precedent to the creep-faulting, since these are made dependent on the gravity-differentiations to which the bulging gives rise. The creep-faulting obviously follows the thrust-faulting in time when the two are thus genetically related, with an interval between. This sequence is believed to be economically important. Compressive stresses may be competent to rive the shell extensively and deeply, but they do not furnish conditions favorable to the gaping of the fissures, in general, but quite the reverse. While the compressive stress is on, the permeation of water, of whatever source, and in whatever direction tending, is antagonized, in the main. Given a pressure equal to 5 or 6 miles of rock-load, and penetration is practically prohibited. Much inferior stresses are competent to force the blocks of the shell into close contact and restrain circulation. Compressive stresses, taken in general, and neglecting attendant special cases, may be serviceable to vein deposition in the preliminary act of fracturing the rock, but to this their immediate serviceability seems to be largely limited.

The succeeding relaxation assigned to creep is, however, precisely the ideal agency required to complete the conditions for free circulation and for the reception of vein deposits and all related deposits. This is not solely limited to those cases in which the ore is deposited in the gaping fissures thus prepared for it, but also includes replacement, impregnation and other deposits which are dependent on the free admission and exit of waters through the avenues opened by the relaxative movement. So

also, in so far as the deposits are dependent on the leaching of the rocks by waters, either superficial or deep, they are probably also largely dependent on the opening of the fractures by the relaxation of the pressure and the setting in of creep. The very slowness of the assigned progress of creep is favorable for the development of vein-filling, for it provides a slowly increasing receptacle for the slow process of deposition. The alternations of tension with minor episodes of compression, incident to the creep process, as previously pointed out, afford a ready explanation of many of the complexities of vein structure, especially those which show successions of growth, with intervening crushing, on the one side, and infalls, on the other.

The length of the interval between the compressive stage and some known phase of the relaxative stage may be such as to be very suggestive, if not decisive, as to the conditions that controlled the ore-deposition. The interval may have been so great and the physiographic changes so notable, as to leave little or no question that the circulation was that controlled by the relaxative conditions in distinction from those of the compressional stage, and it may thus throw the mode of deposition necessarily into the class or classes compatible with the relaxative stages only. This is not a mere academic deduction. It is a conviction forced upon my attention from studies in some of the mining regions of the west. While these studies were of a limited sort, I do not think I am in error in urging attention to the distinction between the conditions of the compressional and relaxative stages in regions of great relief, and to the time interval between these.

The distinction between compressional and tensional conditions is probably also important in studying those ore-deposits that are associated with igneous action. If I am correct in assigning volcanic action to the solution-fusion effected by the rising temperature of the middle zone, and in supposing that the fluid material is forced to the surface about as fast as formed by the differential stresses of the tides and other agencies, effusions of lava should be liable to take place at almost any stage of the earth's history, compressional or relaxative, and this is

the general import of the geologic record. If the lava encounters the crust in a compressional condition, its egress is not only hampered but it is forced to occupy every available cavity and weak spot not only by its own hydrostatic pressure and elastic contents, but by the ascensional stresses which actuate it, and little or no adjacent space or porous rock is likely to be offered for ore depositions, which are thus constrained to limited diffusions and impregnations of the environing formation and to segregations within the lava itself. Not only this, but the prevailing compressional condition tends to prevent the opening of fissures after the lava has so far solidified as to prevent its occupying the fissures itself, and hence the secondary conditions that normally follow an igneous invasion are delayed. Almost the only line of relief from these restraining conditions is found in the doming of the shell above the intrusion with incidental tensional openings.

On the other hand, lava seeking exit through the crust when in a tensional state and affected by open fissures, is less forced to strenuous insinuation, and is more liable to leave minute fractures and porous zones uninvaded. Through these, magmatic waters may go out and meteoric waters may come in and promote deposition. As soon as the exterior of the molten mass cools and its penetration of the adjacent formation is stopped, fissures may freely be opened by the progressive relaxation normal to the tensional state, and circulation outward and inward be facilitated, while at the same time appropriate receptacles for the ores are prepared by the mechanics of relaxation and by the solvent action which the free circulation permits.

Because of these and similar considerations, I believe that if we can reach the heart of the major phenomena of tensional and compressional faulting, we will be on the road to the elucidation of one of the great classes of ore deposition, while the mechanics of faulting will find their solution as a necessary incident.

T. C. CHAMBERLIN.

RECENT LITERATURE ON ECONOMIC GEOLOGY.

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7. **Recent Advances in the Knowledge of the Geology of Western Australia.** By A. G. MAITLAND. Pp. 37–66.
8. **Prevention of External Corrosion of Goldfield's Water Supply Pipes.** By E. S. SIMPSON. Pp. 67–81.

Kontaktmineralien aus der Umgebung von Friedeberg in Schlesien. By AUGUST ROSIWAL. Verhandl. k. k. geol. Reichsanst. 20. March, 1906. No. 5. Pp. 141–146. (Abstract in N. Jahrb. f. Min., Geol., u. Pal.

SCIENTIFIC NOTES AND NEWS[1]

CENTENARY OF THE GEOLOGICAL SOCIETY OF LONDON.

THE GATHERING OF GEOLOGISTS from all parts of the world which assembled in London at the close of last September on the invitation of the Geological Society of London, for the purpose of celebrating its centenary was one of more than ordinary interest.

This Society, which is believed to be the oldest in existence, was founded in the year 1807, at a time when the science of geology, as we now understand it, could be scarcely said as yet to exist, and to this Society is mainly due the conversion of geology from a body of mere speculation to an ordered science.

The aim of the Society was expressed in the fine passage from Bacon which it adopted as its motto: "If any man make it his delight and care not so much to cling to and use past discoveries as to penetrate to what is beyond them, and to conquer not by talk but by toil, in short, not to have elegant and plausible theories, but to gain sure and demonstrable knowledge, let such men (if it shall seem to them right) as true children of knowledge unite themselves with us."

When we reflect that, following this line of advance, the whole science of geology has grown up within the last one hundred years, until now in every University in the world worthy of the name the science finds an honorable place in the curriculum, while in every civilized country the Geological Survey is a regular department of the government service, and the services of the geologist are everywhere regarded as indispensable in con-

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

nection with the development of great mining enterprises,—we cannot but be struck with the place which geology has won for itself among its sister sciences in the short space of a single century.

The occasion was, therefore, one well worthy of commemoration.

Over one hundred delegates from various leading scientific bodies in eighteen foreign countries, as well as from all the dependencies of Great Britain, together with an equal number of representatives from the leading societies of Great Britain and Ireland, assembled in London on September 25th, the meeting lasting until the 28th.

For the week previous to the meeting, however, a series of five excursions had been arranged under the leadership of various British geologists. These excursions, each of which was to occupy the entire week, were to visit different portions of Great Britain, thus affording the visitors an opportunity of seeing those phases of the geology of the British Isles in which they were most interested. Only two or three of these excursions, however, were held, since the delegates as a general rule arrived in England too late to avail themselves of them.

One of the most important of the excursions was that which visited the English Lake District under the able leadership of Dr. J. E. Marr and Professor E. J. Garwood. The thirteen participants started from Coniston and visited Ambleside, Keswick, Penrith, Shap, Appleby and Keisley. The district is one in which there is an enormous and most striking development of volcanic flows with ash beds and breccia of Ordovician age (Borrowdale series) as well as a fine development of the Carboniferous. The Shap granite and its products of metamorphism are also of the highest interest, as are also certain physiographic problems which the district presents. In addition to its geological interest, the district is one which will ever be associated with the names of Ruskin, Wordsworth and Coleridge, and is also from the standpoint of landscape one of the most beautiful in England. The members of the party who were fortunate enough to take part in this excursion felt themselves

greatly indebted to the leaders of the party for a most instructive and enjoyable visit to an interesting district.

In London, the Society's rooms at Burlington House were used as headquarters for purposes of registration and as a general meeting place. The lecture hall of the Society, however, was not large enough to accommodate the delegates and the fellows of the Society. The formal meetings were accordingly held in the house of the Institute of Civil Engineers, Great George Street, Westminster, which was admirably suited for this purpose.

On the morning of September 26 the opening meeting was held at Great George Street. The delegates of each nation were seated by themselves in the alphabetical order of the names of their countries. The chair was taken by Sir Archibald Geikie, the President of the Geological Society of London, and each national delegation was presented to him in turn, one representative of each nation conveying felicitations on the part of his country, in an address in each case limited to three minutes, after which the various members of the delegation handed to the President the formal written address which had been sent through them by their respective institutions. In this way the whole proceeding was carried out with all due ceremony and at the same time with dispatch.

The largest delegations were those from France, Germany, the United States and the British dependencies. These were approximately equal in numbers, that from France being, however, somewhat larger than the others, consisting of nineteen delegates. Throughout the meeting, on account of their numbers as well as owing to the recently established *entente cordiale,* the French delegates were given a place of special prominence, a place as welcome as it was unusual in such international meetings of geologists, their " doyen " being Professor de Laparent.

The representatives from the United States were Professor W. M. Davis, Professor W. B. Clark, Dr. J. M. Clarke, Professor J. P. Iddings, Professor R. S. Tarr, Professor S. W. Williston, Professor C. K. Leith, Dr. Arnold Hague, Dr.

Marsden Manson, Professor J. J. Stevenson, Dr. Whitman Cross, Dr. G. F. Becker and Dr. G. R. Weiland.

Canada was represented by Dr. H. M. Ami and Professor F. D. Adams, and Mexico by Dr. José G. Aguilera.

Dr. Arnold Hague conveyed the congratulations of the geologists of the United States in an excellent and appropriate speech.

Dr. Adams, speaking on behalf of the whole group of British Colonies and Dependencies, had perhaps the most comprehensive task assigned to him, that of conveying the felicitations of 340,000,000 persons in three minutes.

In the afternoon Sir Archibald Geikie delivered his address on "The State of Geological Science at the time of the founding of the Geological Society of London," while in the evening the delegates were entertained at a magnificent dinner in the Whitehall Rooms of the Hotel Metropole.

On the following day, September 27, arrangements were made for the visitors to see St. Paul's Cathedral, South Kensington Museum, the British Museum in Bloomsbury Square, the Museum of the Geological Survey and other places of interest, while in the evening the Geological Club entertained the delegates at a charming dinner held at the Criterion, which was followed by a very brilliant reception in the Museum at South Kensington.

On Saturday, September 28, a number of single day excursions were arranged to various points of geological interest in the vicinity of London. On one of these, to the Northampton iron ore district, the visitors were able to see something of the extensive workings which are being carried on for the purpose of obtaining limonite and siderite in the district about Burton Latimer, Cranword, St. Johns and Slipton. The ores here lie in a well-defined bed, averaging about nine feet in thickness, immediately above the Lias. The ore is non-bessemer, containing from 25 to 56 per cent. of iron. It lies very near the surface and is won chiefly in open workings, the Northampton district producing annually about 6,000,000 tons. One of the most striking features in connection with the winning of this ore is that, although so large an amount of ore is extracted, scarcely any signs of working

are seen in driving through the country. This is due to the fact that the ore is worked in a narrow cut, the over-burden being stripped from the surface of the iron ore on one side and thrown across the cut on to the place from which the ore has been removed on the other. In this way the working face advances across the surface of a tract of fine agricultural country, without in any way interfering with the progress of agricultural operations or with the fertility of the district, for the newly made land becomes at once available again for agricultural purposes and furnishes a crop one year after the iron ore has been removed from beneath it.

On September 29 Mr. Whittaker conducted a large excursion attended by over fifty persons, to Caterham, Godstone and Tilberstow for the purpose of examining the Lower Cretaceous of that district.

The meeting in London having been brought to a close, invitations were extended to the foreign and colonial delegates to visit the Universities of Oxford and Cambridge, these two great seats of learning dividing the visitors between them. At these Universities the visitors for the most part went into residence at the various colleges and were thus enabled to see something of college life in the universities. Here again receptions and dinners were the order of the day, and the visitors experienced the same cordial and abounding hospitality which throughout characterized the whole celebration.

At Cambridge honorary degrees were conferred upon Professor H. Credner, Professor W. C. Broegger, Professor A. G. Nathorst, Professor A. A. de Lapparent and Dr. L. Dollo, while at Oxford Professor A. Heim, Professor A. Reuss, Professor A. Lacroix, Professor C. Barrois, Professor A. Penck, as well as Dr. L. Mond, who was nominated by the chancellor at the last commemoration, but at that time was unable to attend, were similarly honored.

In view of the very prominent place in geological science occupied by the United States, it was a matter of surprise and regret that the name of no representative of that country ap-

peared in the list of those, upon whom degrees were conferred by either university.

These very interesting visits to the old universities brought the celebration to a close.

This centenary celebration offered a very pleasant contrast to other international gatherings, in several respects. Among these two are especially worthy of mention. In the first place, the delegates coming together by invitation were all geologists of some note, and the work of the convention was not impeded by the presence of a large number of persons who had no interest in the proceedings beyond that of the mere pleasure seeker. The omission of a long series of papers was also a distinct advantage, since in international gatherings the papers presented as a general rule are quite unworthy of the occasion and serve chiefly to interfere with the main purpose of the gathering, namely, an opportunity of personal intercourse between workers who seldom meet and whose fields lie in widely separated portions of the world.

F. D. ADAMS.

MR. GEORGE I. ADAMS, formerly of the United States Geological Survey, who has spent the past three and one half years in Peru, employed by the Government and also in private work, returned to Washington in November.

MR. E. C. SULLIVAN, of the United States Geological Survey, was in Joplin, Mo., at the time of the Tenth Annual Mining Congress, making plans preparatory to taking up experimental laboratory work on the chemical processes of ore deposition.

FIFTY THOUSAND DOLLARS, appropriated by the Fifty-eighth Congress for the determination of the character and extent of the coal deposits in Indian Territory in the segregated lands of the Five Civilized Tribes, is now being expended. The extent of the coals is being tested by diamond drill operations, several drilling outfits already being on the ground. It is expected that the present appropriation will continue the work about one and one half years, when information will be at hand for determining the

rates at which the land may be sold or leased. A thorough knowledge of the underground stratigraphy will be obtained by the keeping of accurate detailed drill records. The geologic work is under the general charge of Mr. Joseph A. Taff, of the United States Geological Survey, and the drilling under the immediate supervision of Mr. A. W. Thompson, who has had considerable experience in diamond drilling for coal in the southern Indiana field previous to his present engagement.

C. W. HAYES, Chief Geologist of the Federal Survey, returned to the office the middle of November, after having spent the greater part of the summer in the field. His most recent work was a visit to the bauxite deposits in Georgia and Alabama, and to a number of recently discovered deposits of the same ore in Tennessee which considerably expand the extent of the deposits previously known.

DR. DAVID T. DAY, who attended the International Petroleum Congress in Roumania, and has returned to Washington for the winter, reports most important advances in the technology of petroleum refinement, which will be of the highest importance to the petroleum industry in this country. Dr. Day is now devoting his time to the development of more economical methods of the utilization of crude petroleum.

MR. J. S. DILLER, of the Federal Survey, assisted by G. F. Kay, was engaged in investigations in Oregon during the past summer. The Riddles quadrangle was completed and work begun on the Grants Pass quadrangle. A special investigation was made of several townships in the Siskiyou National Forest in which coal claims had been reported. A report on these townships is in preparation, samples of the coal being tested at the Survey laboratories in Pittsburg and Denver. Also they examined a small mineral belt in T31S, R9&10W, about 50 miles northwest of Grants Pass, in which there are interesting copper and gold prospects and placers. His report on this belt has already been given circulation in the newspapers.

W. T. GRISWOLD, who has worked for several years in the oil fields of Pennsylvania and Ohio, has resigned from the U. S.

Geological Survey and entered the oil business, with offices at Pittsburg, Pa.

COOPERATIVE GEOLOGIC WORK IN PENNSYLVANIA this year was under the direction of Geo. H. Ashley. Besides visiting the various parties in the field, Mr. Ashley gave some time to stratigraphic problems in the Punxsutawney and Houtsdale quadrangles, and also made trips to coal fields in Illinois, Kentucky and West Virginia. Chas. Butts mapped the geology of the Warren quadrangle, E. F. Lines finished the Clarion quadrangle, and G. C. Martin, F. B. Peck and M. J. Munn completed the geology of the Carnegie quadrangle. Also Mr. Munn finished the geology of the Claysville and Sewickley quadrangles and Mr. Martin obtained additional data on the geology of the Burgettstown quadrangle. When this material is published there will be made available a great amount of detailed information concerning the occurrence of coal, gas, and oil in the extensive fields of western Pennsylvania.

F. W. DEWOLF, E. F. LINES, and E. F. BURCHARD are investigating coal, clay, and other mineral resources in Illinois under the direction of State Geologist H. F. Bain. Their address is State Geological Survey, Urbana, Ill.

MESSRS. G. O. SMITH, A. H. Brooks, M. R. Campbell, E. W. Parker, W. Lindgren, F. L. Hess, and C. E. Siebenthal, of the U. S. Geological Survey, attended the 10th annual Mining Congress at Joplin, Mo., the week of November 11.

WHITMAN CROSS returned to Washington early in November after spending the summer in Europe.

A. J. COLLIER, OF THE U. S. GEOLOGICAL SURVEY, who examined the new tin prospect near Spokane, Washington this summer, reports that on the dump there is probably the biggest pile of tin ore in the United States, and that the prospect justifies further exploitation, although the deposit is irregular and indefinite. The occurrence of tin is unique at this locality, the association of minerals being an unusual one for tin ores. Development of the prospect will progress through the winter and Mr. Collier will prepare a brief report for early publication.

MR. S. F. EMMONS was engaged during the past summer in Mexico in a geological survey of the Cananea mining district for the Cananea Consolidated Copper Company. He was assisted by J. M. Boutwell, L. C. Graton, and W. H. Emmons.

WILLIS T. LEE, of the U. S. Geological Survey, spent the summer in an investigation of the Grand Mesa coal field in western Colorado. This field is an immense lava-covered mesa lying between the Grand and Gunnison rivers, a region as yet very little known. Mr. Lee made a topographic and geologic map covering several hundred square miles along the outcrop of the coal-bearing and contiguous formations. Numerous large beds of coal ranging from low to high grade were found. In the eastern part of the field on the slope of Elk Mountains there are at least 13 workable beds, the largest of which is 40 feet thick. Another bed is 14 feet thick and several others range in thickness from 8 to 10 feet. These are largely bituminous and some are coking coals. In the vicinity of the mountains adjacent to igneous activity they are turned to anthracite. Active mining in this field is only just begun and prospecting is progressing rapidly. The land surveys, however, are in such state that prospectors cannot make final entry on land. This hinders development of the field, and a resurvey by the General Land Office is needed. The field promises to be one of the important coal producers of the western States.

MR. BAILEY WILLIS, of the U. S. Geological Survey, was absent on leave during August and September engaged under the auspices of the Smithsonian Institution in a study of the structure of the Alps. Observations in the Front Alps between Lake Geneva and Lake Thun were made in Part with Professor A. Rothpletz, of Munich, and conferences were had with Professor Eduard Suess at Vienna, Professors Lugeon and Jaccard at Lausanne, and Professors Haug and de Margerie at Paris. Overthrusts of great displacement and in part probably of late Pliocene date were studied and in so far the modern views of Alpine structure appear to be sustained. But the overfolds, which are given a dominant place in the theories of Lugeon and

his school, appear rather to be subordinate phenomena, and the piling-up of a succession of *nappes de recouvrement* in the hypothetical synthesis of the Alps does not seem to be justified by any facts observed. The structures are apparently those of major and minor thrusts of the Scotch type, complicated in the Front Alps, at least, by the intersection of earlier thrust planes on which the movement was southeast by later thrust planes on which the advance was northwest. The results of Mr. Willis's observations are to appear in a report to the Smithsonian Institution.

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